National Aeronautics
and Space Administration

December 21, 2001
NRA 01-OBPR-08

RESEARCH ANNOUNCEMENT

RESEARCH OPPORTUNITIES
IN
PHYSICAL SCIENCES

Cellular and Macromolecular Biotechnology
Combustion Science
Fluid Physics
Fundamental Physics
Materials Science
Special Focus Themes

Proposals Due: **March 22, 2002 THROUGH December 2, 2002**

OMB Approval No. 2700-0087

RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

NASA Research Announcement
Soliciting Basic and Applied Research Proposals

NRA 01-OBPR-08
Issued: December 21, 2001

Office of Biological and Physical Research (OBPR)
National Aeronautics and Space Administration
Washington, DC 20546-0001

NOTICE

NEW STRUCTURE AND SOLICITATION SCHEDULE FOR PHYSICAL SCIENCES DIVISION NRA

The Physical Sciences Division of the Office of Biological and Physical Research is changing its schedule for announcement of research opportunities. Beginning with this NASA Research Announcement (NRA), the Physical Sciences Division will issue one annual announcement for all research program elements: Biotechnology, Combustion Science, Fluid Physics, Fundamental Physics, Materials Science, and Special Focus Themes. Due dates for proposals responding to these program discipline elements are specified within this document. This new format and frequency replace the biennial, discipline-specific solicitation structure previously utilized for announcement of research opportunities.

RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

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RESEARCH OPPORTUNITIES IN PHYSICAL SCIENCES

I. INTRODUCTION AND GENERAL POLICIES

NASA is an investment in America's future. Two of the key missions of the Agency to which the subject of this NASA Research Announcement (NRA) directly relates are to advance and communicate knowledge and understanding of the Earth, the solar system, and the universe; and to advance human exploration, use, and development of space. In charting NASA's vision for the future and plan for accomplishing its mission, the Agency has created the NASA Strategic Plan 2000. The plan includes near term priorities, such as construction and operation of the International Space Station (ISS), and longer term investments, including scientific and technological research. In recognizing the revolutionary role of biotechnology in the 21^{st} century and also to take advantage of the unprecedented capabilities of the International Space Station (ISS) for conducting world class physical, chemical, and biological research, NASA created the Office of Biological and Physical Research (OBPR) on October 2, 2000.

The OBPR mission is to use the synergy among physical, chemical, and biological research in space to acquire fundamental knowledge and generate applications for space travel and Earth applications. The goals of NASA's fifth and newest Enterprise are the following:

- Conduct research to enable safe and productive human habitation of space.
- Use the space environment as a laboratory to test the fundamental principles of physics, chemistry, and biology.
- Enable and promote commercial research in space.
- Use space research opportunities to improve academic achievement and quality of life.

The Enterprise seeks to understand the fundamental role of gravity and cosmic radiation in vital biological, physical, and chemical systems in space, on other planetary bodies and on Earth. To accomplish this goal, the Enterprise must determine which technologies, processes, techniques, and engineering capabilities must be developed to enable the OBPR research agenda in the most productive, safe, economical, and timely manner. Finally, OBPR must effectively transfer knowledge from research and discoveries to foster a permanent human presence in space, to benefit commercial ventures, and to improve the quality of human life on Earth.

The Physical Sciences Division (PSD) of OBPR has the responsibility to conduct physical sciences and engineering research that combines unique experimental facilities with long duration access to low-Earth orbit and beyond to overcome gravity-induced limitations and to enable new scientific discoveries. PSD recognizes that revolutionary solutions to the above fundamental questions of science and technology are likely to emerge from scientists, clinicians, and engineers who are working at the frontiers of their respective disciplines and are also engaged in dynamic interdisciplinary interactions. Therefore, the program sponsors and is seeking exceptional quality discipline-based and interdisciplinary ground-based and flight research to drive technological innovation for space exploration and ground-based applications.

The goals of the Physical Sciences Division are to

- Carry out cutting-edge, peer-reviewed, and multi-disciplinary basic research, as enabled by the space environment, to address NASA's goal of advancing and communicating knowledge

- Develop a rigorous, cross-disciplinary scientific capability, bridging physical sciences and biology to address NASA's human and robotic exploration goals

- Establish the International Space Station (ISS) facilities as unique, on-orbit science laboratories addressing targeted scientific and technological issues of high significance

- Enhance the knowledge base that contributes to Earth-based technological and industrial applications

To accomplish these goals, the Physical Sciences Division sponsors a wide spectrum of research programs relevant to its three Research Elements:

Fundamental Microgravity Research

- Combustion science
- Fluid physics
- Fundamental physics
- Materials science
- Exploration research

Biomolecular Physics and Chemistry (Separate announcement will address these elements)

- Atomic and molecular processes in biosystems
- Biological sensing phenomena
- Cellular components assembling mechanisms

Biotechnology and Earth-Based Application

- Cellular biotechnology
- Macromolecular biotechnology
- Earth-based applications

Additional information about OBPR and the Physical Sciences Division, including the Strategic Vision, Research Themes, and the NASA Strategic Plan may be found through the OBPR homepage on the World Wide Web at http://spaceresearch.nasa.gov/. In addition, this NRA may be found through the menu listings *Research Opportunities/Current (Open) Solicitations* at the same Web site.

The specific objectives of the physical sciences research program will be carried out by a broadly-based and multidisciplinary research community recruited from academia, industry, and other Government research agencies through this NASA Research Announcement. Prior to this solicitation, the individual disciplines within the Physical Sciences Division, Biotechnology, Combustion Science, Fluid Physics, Fundamental Physics, and Materials Science, had released separate announcements generally on a biennial basis. Beginning with this announcement, the Physical Sciences Division will issue one annual announcement for all research program elements. These program elements are summarized at a top level in the next section and described in more detail in Appendices B-G. Table 1 lists these program elements in the order of their respective due dates for the submission of proposals. Questions about each element should be directed to the respective Enterprise Discipline Scientist, all of whom are identified in the appropriate Appendix.

Questions about this NASA Research Announcement structure and review of the Physical Sciences Division research program may be sent to

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II. SUMMARIES OF PROGRAM ELEMENTS FOR WHICH PROPOSALS ARE SOLICITED

This section provides top-level summaries of the various research elements, including information pertinent to this solicitation such as research element goals, vision, and program scope. Therefore, anyone interested in applying to this NRA is urged to read the relevant parts of this section to decide whether their research interests are relevant to NASA OBPR/PSD interests, and, if so, to which research element their proposal should be submitted. The appropriate Appendix should then be studied for a more complete understanding of the goals and direction of that program element. <u>It is especially important to note that the overall objective of each of these program research elements is to contribute as effectively and directly as possible to the achievement of OBPR/PSD strategic goals</u>.

Cellular and Macromolecular Biotechnology Program

NASA's Biotechnology program includes both cellular and macromolecular research that supports development of research for the International Space Station and applied research in biotechnology for long-duration space flight. The goals are to advance the scientific understanding of biotechnology processes relevant to NASA, use low-gravity experiments for insight into the physical behavior of biotechnology processes, provide the scientific knowledge needed to improve these processes, contribute to Earth-based systems concerned with biotechnology, and develop technologies specifically supporting NASA activities. NASA's cellular biotechnology program is developing new technologies for the growth of three-dimensional mammalian tissues and supports the development of reduced hydrodynamic-shear bioreactors that provide a model system for the low gravity conditions of space to the extent possible on Earth. The program seeks to 1) accelerate the development of advanced three-dimensional tissue culturing systems to support tissue engineering, 2) define and characterize mammalian cells and tissues that benefit from a low shear environment using gene expression and changes to metabolic function, 3) use the microgravity environment of space as necessary to surmount the obstacles to the propagation of complex tissues, and 4) develop tissue models that support biomedical research in space and on Earth including models for human disease studies and pharmaceutical testing. NASA's macromolecular biotechnology research encompasses a spectrum of research including 1) crystallographic analyses of more complex and challenging systems, such as motor proteins, glycoproteins, and integral membrane proteins by using the space environment; 2) elucidation of the fundamental factors that provide for the observed benefits in diffraction performance when macromolecular crystals are grown in microgravity; 3) development of technologies and quantitative methodologies that will improve structural biology research; and 4) research and development of leading-edge technologies for NASA missions in biomaterials and biological nanotechnology.

Combustion Science Program

The Microgravity Combustion Science activity includes investigations of a wide range of fundamental combustion processes, development of rational design procedures for maximizing efficiency and minimizing pollution associated with combustion processes on Earth, development of novel methods for materials production via combustion, improvement of fire safety at reduced gravity conditions, and development of combustion-related technologies which will aid in the human exploration of space. Current areas of study being funded include 1) Gaseous Flames (Diffusion Flames, Premixed Flames, Partially Premixed Flames, Triple Flames, Flame-Vortex Interactions, Kinetics, Electrical Field Effects, Magnetic Field Effects, Flame Suppression, Edge Flames); 2) Droplets, Sprays, Particles, and Dust Clouds (Single Droplets, Droplet Arrays, Sooting Droplets, Sprays, Particle Combustion, Dust Clouds, Bubble Combustion); 3) Combustion Synthesis (Self-Propagating High-Temperature Synthesis, Fullerene production from Flames, Nanoparticle production from Flames, Agglomerate production from Flames, Plasma Synthesis); 4) Surface Combustion/Fire Safety (Flame Spread Across Surfaces, Flammability Testing, Flame Detection, Extinguishment, Smoldering, Liquid Pool Combustion, Secondary Fires); and 5) Miscellaneous Topics (Cold Boundary Flames, Diagnostics Development, Propellant Combustion).

Fluid Physics Program

The Microgravity Fluid Physics Program encompasses a wide range of research in physics and engineering science, including studies of heat and mass transfer processes, fluid dynamics, the physics of complex fluids, and biological fluids. Fluid mechanics and transport phenomena play a dual role in the microgravity research program. It stands as a distinct area, but also appears as a theme running through other disciplines. The motivation for this research is to enhance our understanding of fluids physics related to basic science, earth applications, space flight, the health and safety of the astronauts, and applications on other planetary bodies. There are currently six major areas in the Microgravity Fluid Physics Program: complex fluids, interfacial phenomena, biofluids, dynamics and instabilities, multiphase flow and heat transfer, and exploration.

Fundamental Physics Program

The Microgravity Fundamental Physics Program encompasses a wide range of research in physics where the space environment offers distinct opportunities for researchers compared to what can be accomplished in ground-based laboratories. There are two main goals for this research program:

- explore and understand the fundamental physical laws governing matter, space, and time; and to
- discover and understand the organizing principles of nature from which structure and complexity emerges.

By looking deeply into the smallest and largest pieces that make up the fabric of our universe, we will understand better our basic ideas that describe the world. While the basic laws of nature may be simple, the Universe that has arisen under these laws is amazingly complex and diverse. By studying nature apart from Earth's gravity, we can understand better how the Universe developed.

There are currently five major areas in the Microgravity Fundamental Physics Program: low temperature and condensed matter physics, laser cooling and atomic physics, gravitational and relativistic physics, biological physics, and science enabling technology development and support of NASA's exploration goals.

Materials Science Program

The Materials Science Program currently supports research in a broad range of areas. The Materials Science Discipline Working Group (DWG), an advisory body to NASA's Physical Sciences Division, has identified research areas, classified in terms of fundamental physical and chemical phenomena, that it believes would benefit from access to long-duration, high-quality microgravity conditions. Also included in the recommended research areas are those activities that the DWG believes are required to fully realize the potential of microgravity research (e.g. process modeling, materials characterization, etc.). The recommended research areas are 1) Thermodynamics and kinetics of phase transformation; 2) Theory, modeling, and experimental control of microstructure and defect formation; 3) Interfacial phenomena; and 4) Measurement of relevant material properties. In addition to these areas of Materials Science, research in areas that support NASA's exploration goals are a priority. Specifically, these are radiation shielding appropriate for long-duration lunar or Mars missions, and the effects of gravity on the materials processes necessary to convert resources found on other bodies of the solar system into usable commodities. Since research in biomaterials and radiation shielding has only recently been solicited by PSD, research in those areas will not be considered in this announcement. These topics will be solicited in the PSD NRA to be released in Winter of 2002.

Special Focus Theme: Materials Science for Advanced Space Propulsion

A workshop was recently conducted with representatives of the Office of Aerospace Technology, Office of Space Science, the Physical Sciences Division, and the materials science research community to identify areas in advanced space propulsion that would benefit from fundamental research in materials science. Extensive discussions sought to ensure that recommended research topics were directly related to an important problem in advanced space propulsion, had an identified NASA customer, and had a time scale such that they would benefit from results of basic research. Based on the results of this workshop, the materials science program seeks to support basic research in the following thematic areas as related to advanced space propulsion:

- Enabling materials
- Enabling processes
- Research enabled by, or that derives significant benefit from, access to space
- Establishment of Cornerstone Knowledge

Please refer to Appendix G to obtain a more detailed description of each thematic area.

Short descriptions of all investigations in all disciplines being funded by PSD as of FY2000 may be found in the PSD FY2000 Task Book at:
http://peer1.nasaprs.com/peer_review/taskbook/taskbook.html

III. SELECTION CATEGORIES (GROUND, FLIGHT)

Proposals selected for support through this NRA will generally be designated as either ground-based or flight definition investigations. (Other categories may be identified within specific program elements.) Investigators offered support in the ground-based program normally will be required to submit a new proposal for competitive renewal after no more than four years of support. Investigators offered flight definition status are expected to begin preparing detailed experiment requirements and concepts for flight experiment development shortly after selection in cooperation with the assigned representative from the appropriate NASA Center. Selected investigations will be required to comply with NASA policies, including the return of all appropriate information for inclusion in the NASA archives during the performance of and at the completion of the contract or grant.

Commitment by NASA to proceed from flight definition to the execution phase of a flight experiment will be made only after several additional engineering and scientific reviews and project milestones have established the feasibility and merit of the proposed experiment. Investigations that do not pass these reviews will be funded for a limited period (generally no more than four years from the initial award date) to allow an orderly closure of the project.

The Principal Investigator in flight definition must prepare a Science Requirements Document (SRD) early in the development of a flight experiment to guide the design, engineering, and integration effort for the instrument. The SRD describes specific experiment parameters, conditions, background, and justification for flight. Ground-based, normal, and reduced-gravity experimentation, as well as any necessary parallel modeling efforts, may also be required to prepare an adequate Science Requirements Document. The amount of support (technical, scientific, and budgetary) provided to investigators by NASA will be determined based upon specific investigator needs and the availability of resources to NASA and PSD.

IV. GUIDELINES FOR INTERNATIONAL PARTICIPATION

(1) NASA welcomes proposals from outside the U.S. However, foreign entities are generally not eligible for funding from NASA. Therefore, unless otherwise noted in the NRA, proposals from foreign entities should not include a cost plan unless the proposal involves collaboration with a U.S. institution, in which case a cost plan for only the participation of the U.S. entity must be included. Proposals from foreign entities and proposals from U.S. entities that include foreign participation must be endorsed by the respective government agency or funding/sponsoring institution in the country from which the foreign entity is proposing. Such endorsement should indicate that the proposal merits careful consideration by NASA, and if the proposal is selected, sufficient funds will be made available to undertake the activity as proposed.
(2) All foreign proposals must be typewritten in English and comply with all other submission requirements stated in the NRA. All foreign proposals will undergo the same evaluation and selection processes as those originating in the U.S. All proposals must be received before the established closing date. Those received after the closing date will be treated in accordance with NASA FAR Supplement 1852.235-72(g). Sponsoring foreign government agencies or funding institutions may, in exceptional situations, forward a proposal without endorsement if endorsement is not possible before the announced closing date. In such cases, the NASA sponsoring office should be advised when a decision on endorsement can be expected.
(3) Successful and unsuccessful foreign entities will be contacted directly by the NASA sponsoring office. Copies of these letters will be sent to the foreign sponsor. Should a foreign proposal or a U.S. proposal with foreign participation be selected, NASA's Office of External Relations will arrange with the foreign sponsor for the proposed participation on a no-exchange-of-funds basis, in which NASA and the non-U.S. sponsoring agency or funding institution will each bear the cost of discharging their respective responsibilities.
(4) Depending on the nature and extent of the proposed cooperation, these arrangements may entail

- (i) An exchange of letters between NASA and the foreign sponsor; or
- (ii) A formal Agency-to-Agency Memorandum of Understanding (MOU).

As stated above, non-U.S. proposals accepted under this NRA will be implemented on the customary no-exchange-of-funds basis, in which NASA and the sponsoring non-U.S. agency will each bear the cost of discharging their respective responsibilities. Additionally, NASA funding may not be used to purchase a launch service from a non-U.S. source. However, the direct purchase of goods and/or services from non-U.S. sources by U.S. Principal Investigators or U.S. Co-Investigators is permitted. Investigators are advised that international purchases must meet NASA and Federal regulations, including those relating to export and import control, and that these regulations may place an additional burden on the successful investigator that should be explicitly included in discussions of the proposed budget. U.S. proposals including foreign participation must include a section discussing compliance with U.S. export laws and regulations, e.g., 22 CFR Parts 120–130 and 15 CFR Parts 730–774, as applicable to the circumstances surrounding the particular foreign participation. The discussion must describe in detail the proposed foreign participation and is to include, but not be limited to, whether or not the foreign participation may require the prospective investigator to obtain prior approval of the Department of State or the Department of Commerce via a technical assistance agreement or an export control license, or whether a license exemption/exception may apply. If prior approval via licenses is necessary, discuss whether the license has been applied for or, if not, the projected timing of the application and any implications for the schedule. Information regarding U.S. export regulations is available at http://www.pmdtc.org/ and http://www.bxa.doc.gov/ . Investigators are advised that under U.S. law and regulations, spacecraft and their specifically designed, modified, or configured systems, components, and parts are generally considered “Defense Articles” on the United States Munitions List and subject to the provisions of the International Traffic in Arms regulations (ITAR), 22 CFR Parts 120–130.

V. OBPR POLICY FOR EDUCATION AND PUBLIC OUTREACH

NASA envisions that the selected proposals will be structured and operated in a manner that supports the country’s educational initiatives and goals (including historically black colleges and universities and other minority universities), and in particular the need to promote scientific and technical education at all levels. NASA envisions that the selected proposals will support the goals for public awareness and outreach to the general public.

In support of the OBPR goal to “use space research opportunities to improve academic achievement and the quality of life,” individuals participating in the physical sciences program are encouraged to help foster the development of a scientifically informed and aware public. The physical sciences program represents opportunities for NASA to inspire students and teachers to “reach for the stars,” to enhance the Nation’s formal education system, and to broaden the public’s understanding and appreciation of the value of research in the microgravity environment of space. PSD’s demonstrated contributions to education and outreach have now become an important part of the broader justification for the public support of microgravity science research (for further details open *Education* on the OBPR homepage at the Web site provided above). Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and physical sciences research conducted under microgravity conditions through formal and/or informal education opportunities.

Proposals should include a clear and concise description of a plan for education and outreach activities. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula consistent with educational standards.

The selected investigators are invited to participate in NASA-funded educational programs. Where appropriate, the supported institution will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

VI. NEW INSTRUCTIONS FOR PREPARATION/SUBMISSION OF PROPOSALS

In May 2001, NASA published a comprehensive, unified set of guidelines describing the policies and procedures of the Broad Agency Announcement used by the National Aeronautics and Space Administration known as the NASA Research Announcement (NRA). This publication is entitled *Guidebook for Proposers Responding to a NASA Research Announcement.* The most recent edition of this Guidebook can be found by following links through the NASA World Wide Web homepage at http://www.nasa.gov or more directly from http://www.hq.nasa.gov/office/procurement/nraguidebook/propgdbk.pdf. This standardization has proven to be of significant value to NASA to help ensure the uniform handling and processing of submitted proposals, as well as to researchers interested in responding to multiple program elements.

By reference, this *Guidebook for Proposers Responding to a NASA Research Announcement* is hereby incorporated into this NRA. All investigators to this NRA are responsible for understanding and complying with its procedures before preparing and submitting their proposals. In particular, its Chapter 2 ("Proposal Preparation and Organization") and Chapter 3 ("Proposal Submission Procedures") largely replace the contents of "Appendix C" in most OBPR/PSD (formerly Office of Life and Microgravity Sciences and Applications) NRAs issued during the previous three years. Also, note that the NASA-required proposal *Budget Summary* form is now available electronically through the Web site specified in the NRA directly following the *Cover Page/Proposal Summary* for printing in hard copy for submission with the hard copies of the proposal. The other chapters and appendices of this *Guidebook for Proposers Responding to a NASA Research Announcement* provide supplemental information about the entire NRA process, including NASA policies for the solicitation of proposals (including those involving non-U.S. participation), guidelines for writing complete and effective proposals, the NASA policies and procedures for the proposal review and selection processes and for issuing and managing the awards to the institutions that submitted selected proposals, and Frequently Asked Questions (FAQs) about a variety of proposal and award processes and procedures.

OBPR has recently converted to a new electronic proposal handling system designated SYS-EYFUS. This system, whose usage by the investigator is described in much more detail in Appendix A, is to be used for electronic submission of a Notice of Intent (NOI) to propose and for preparation and electronic submission of the Cover Page/Proposal Summary and Budget Summary of the proposal itself (Chapters 2 and 3 of the *Guidebook for Proposers Responding to a NASA Research Announcement* as discussed above contain more detailed information about these two items). **In order to make full use of this electronic system, it is necessary for the investigators (Principal Investigator and Co-Investigators) to register in the SYS-EYFUS system; instructions for doing so are included in Appendix A.** The SYS-EYFUS Web site will be open for the submission of NOIs for any given program element in this NRA for (typically) 45 days, starting about 90 days before the proposal due date, and the site will be open for the submission of the other required proposal materials starting about 45 days before the proposal due date (see Table 1 below for all schedules). A point of contact for assistance in accessing and/or using this Web site is given in the Summary Information of Section IX.

Although, as stated above, the investigator is responsible for understanding and complying with the Guidebook, a brief summary of what should be included in your proposal is presented here for the benefit of the investigator. Proposals submitted in response to this Announcement must be typewritten in English, **should not exceed 20 pages in length, exclusive of appendices and supplementary material, should be typed on 8-1/2 x 11 inch paper with a 10 or 12 point font**, and should contain at least the following elements (in order):

(1) Standard Cover Page and Summary (The summary should succinctly convey, in broad terms, what it is the investigator wants to do, how the investigator plans to do it, why it is important, and how it meets the requirements for programmatic relevance and/or relevance to OBPR goals)—Standard forms to be obtained from the SYS-EYFUS Web site discussed in Appendix A

(2) Budget Summary—Standard forms also to be obtained from SYS-EYFUS

(3) Table of Contents

(4) Research Project Description containing the following elements:

a. Statement of the hypothesis, objective, and value of this research.
b. Review of relevant research.
c. Justification of the need for low gravity or a space environment to meet the objectives of the experiment.
d. Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.
e. Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.
f. A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based, reduced-gravity facilities (flight definition proposals only).
g. A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and durations, control and diagnostic measurement requirements, etc.

(5) Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants

(6) A clear and concise description of the proposed plan for education and public outreach activities, not to exceed 5% of the budget. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula. Proposed K-12 related education activities should adhere to and identify relevant education standards

(7) **Prior Period of Support.** For follow-on proposals of ongoing PSD**-**sponsored projects, a summary of the objectives and accomplishments of the prior period of support, including a list of published papers derived from that support, must be included as part of the investigator's justification for continued support. (Supplementary material)

(8) Summary of current and pending support for the Principal Investigator and Co-Investigators**. If the investigator is currently performing similar work under funding from another government agency, he/she must clearly explain the difference between this proposed project and the other work.** (Supplementary material)

(9) Complete current curriculum vitae for the Principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants. (Supplementary material)

VII. REVIEW PROCESS AND EVALUATION CRITERIA

The evaluation process for this NRA will be based on a peer review of the proposal's intrinsic scientific and technical merit, articulated relevance to the Physical Sciences program, and cost of the research plan. The reviewers will be scientific and technical experts from government, academia, and industry. Each proposal will be reviewed independently by members of the review panel and discussed at a review panel meeting to determine a consensus evaluation for the proposal. For flight definition proposals, NASA will also conduct engineering and management reviews to establish feasibility of the planned implementation, to review risk mitigation plans, to evaluate the experience of the implementing organization, and to review the budget. The external peer review and internal engineering review panels will be coordinated by the NASA Enterprise Discipline Scientists. Consideration of the programmatic objectives of this NRA will be applied by

NASA to ensure enhancement of program breadth, balance, and diversity. NASA will also consider the cost of the proposal. The PSD Director will make the final selection based on science panel evaluations and programmatic recommendations.

Upon completion of all deliberations, a selection statement will be released notifying each investigator of proposal selection or rejection. Offerors whose proposals are declined will have the opportunity of a verbal debriefing with a NASA representative regarding the reasons for their not being selected for award. In all cases, the Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment can be made, and upon the receipt of proposals in response to this NRA that NASA determines are acceptable for award. Additional information on the evaluation and selection process is provided below and in the *Guidebook for Proposers Responding to a NASA Research Announcement,* previously referenced. The most recent edition of this guidebook can be found by following links through the NASA World Wide Web homepage at http://www.nasa.gov or by going directly to the Web address given in Sections VI and IX.

The principal elements considered in the evaluation of proposals solicited by this NRA are relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, which has slightly lesser weight. Both of these elements have greater weight than cost. Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

- Overall scientific or technical merit, including evidence of unique or innovative methods, approaches, or concepts, the potential for new discoveries or understanding, or delivery of new technologies or products and associated schedules.
- Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives.
- Institutional resources and experience that are critical in achieving the proposal objectives.
- Proposed plan for education and public outreach activities. Examples include such items as involvement of students in the research activities, technology transfer plans, public information programs that will inform the general public of the benefits being gained from the research, and/or plans for incorporation of scientific results obtained into educational curricula, including compliance with relevant education standards.
- Overall standing among similar proposals available for evaluation and/or evaluation against the known state-of-the-art.

Recommendations for funding for the proposals submitted to this NRA will be based on the peer evaluation of each proposal, programmatic balance, and cost. The scientific peer review panel will assign each proposal a numerical merit score based on the above factors. The score assigned by the peer review panel will not be affected by the cost of the proposed work nor will it reflect the programmatic relevance of the proposed work to NASA. However, the panel will be asked to include in their critique of each proposal any comments they may have concerning the proposal's budget and relevance to NASA. For flight proposals, the engineering and management panel will evaluate the feasibility and complexity of accomplishing each investigation along with an estimate of total cost for flight hardware development. NASA will take these assessments into consideration in making the final selection of experiments that will be considered for flight definition.

Evaluation of the cost of a proposed effort includes consideration of the realism and reasonableness of the proposed cost and the relationship of the proposed cost to available funds. NASA reserves the right to act in the best interest of the federal government in the matter of proposal evaluation and funding. NASA reserves the right to determine the funding mechanism for any proposal selected for funding.

Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

The following questions should be kept in mind by investigators when addressing the relevance to NASA's scientific and programmatic objectives:

1) Is the space environment of fundamental importance to the proposed study, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter, or in providing access to conditions not available on Earth?
2) Do the issues addressed by the research have potential to close major gaps in the understanding of fundamentals of the cognizant discipline or to cross-disciplinary interactions?
3) Is there potential for elucidation of previously unknown phenomena?
4) Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving the basic disciplines or cross-disciplinary interactions?
5) Are the results likely to be broadly useful, leading to further theoretical or experimental studies?
6) Does the proposal represent a ground-breaking advance or is it merely incremental relative to the current state-of-the-art?
7) Is the project technologically feasible, without requirements for substantial new technological advances?
8) How will this project stimulate research and education?
9) How does the projected cost/benefit ratio compare with other projects competing for the same resources?
10) What is the potential of this project in terms of stimulating future technological "spin-offs"?
11) Are there strong, well-defined linkages between the research and OBPR/PSD goals?

Participation in this program is open to all categories of U.S. and non-U.S. organizations, including educational institutions, industry, nonprofit institutions, NASA Centers, and other Government agencies. Historically Black Colleges and Universities (HBCUs), other minority educational institutions, and small businesses and organizations owned and controlled by socially and economically disadvantaged individuals or women are particularly encouraged to apply.

VIII. ITEMS OF SPECIAL IMPORTANCE FOR THIS NRA

(1) Because this Physical Sciences NRA is being released far in advance of many of the deadlines given in Table 1, additional programmatic information for any given entry may develop before proposals are due. If so, such material will be added as an Amendment to this NRA as posted at its NRA Web site no later than 90 days before the proposal deadline. Although NASA OBPR/PSD will also send an electronic alert of any such amendments to all subscribers of its electronic notification system (see Special Note (3) below), it is the responsibility of prospective investigators to check this NRA Web site for updates concerning the program element(s) of interest.

(2) OBPR/PSD now requires the electronic submission of certain key elements of proposals through the World Wide Web (see below in the Summary Information), and this practice continues with this NRA. While every effort is made to ensure the reliability and ease of accessibility of this Web site, and to maintain a point of contact for assistance via e-mail, difficulty in accessing and/or using this site may arise at any point on the Internet including the user's own equipment. Therefore, prospective investigators are urged to

familiarize themselves with this site well in advance of the deadline(s) of the program element(s) of interest.

(3) OBPR maintains an electronic notification system to alert interested subscribers of the impending release of its research program announcements and amendments. Subscription to this service is accomplished through the menu item *Research Opportunities* on the OBPR home page at http://spaceresearch.nasa.gov by following the instructions to *Add yourself to the OBPR mailing list.* This requires registration (including specification of your fields of interest) in the SYS-EYFUS database (previously referenced and described in detail in Appendix A). Regardless of whether this service is subscribed to or not, all OBPR research announcements may be accessed from the Web as soon as they are posted (about 8:30 a.m. Eastern Time on the day of release) through *Research Opportunities* on the OBPR homepage.

IX. SUMMARY INFORMATION APPLICABLE TO THIS NRA

- Program alphanumeric identifier: NRA 01-OBPR-08

- Date of NRA issue: December 21, 2001

- Period of Funding: Up to 4 years unless otherwise specified for a given discipline

- Guidance for preparation and submission of proposals:

  Guidebook for Proposers Responding to a NASA Research Announcement at http://www.hq.nasa.gov/office/procurement/nraguidebook/propgdbk.pdf

- Submission of *Notice of Intent* (NOI) to propose:

  Due date: See Table 1 below for program element of interest (typically 60 days prior to the Proposal Deadline)

  Web site for electronic submission:
  http://proposals.hq.nasa.gov
  Contact for assistance: Help Desk at 202-479-9376

- Electronic submission of the proposal's *Cover Page/Proposal Summary*

  Deadline: See Table 1 below for program element of interest.

  Web site for electronic submission:
  http://proposals.hq.nasa.gov
  Contact for help: Help Desk at 202-479-9376

- Web site for download of proposal *Budget Summary* form:

  http://proposals.hq.nasa.gov
  Contact for help: Help Desk at 202-479-9376

- Renewal Proposals

  Renewal proposals should not rely on references to previous proposals for any information required for a complete proposal. **It is particularly important that**

investigators who seek to extend an existing NASA research activity that is relevant to this NRA submit a proposal that clearly identifies and documents achievements on their current effort and how the work proposed in the current proposal supports their request for additional sponsorship. Such follow-on proposals will be reviewed on an equal basis with all other submitted proposals.

- Submission of hard copy of proposals:

  Page limits:

  The proposal should not exceed 20 pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11 inch paper in a 10- or 12-point font. Extensive appendices and ring-bound proposals are discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal, with the understanding that the reviewer is not required to read them.

  Required number: Signed original plus 15 copies

  Deadlines: 4:30 p.m. Eastern Time on dates in Table 1

- Address for submission by U.S, Postal Service, commercial delivery, or courier:

  Name of Program Element
  Physical Sciences Division NRA
  NASA Peer Review Services
  Suite 200
  500 E Street SW
  Washington, DC 20024
  Telephone: 202-479-9030

- Selecting Official: Dr. Eugene Trinh, Director
  Physical Sciences Division
  Office of Biological and Physical Research

- Announcement of selection: 180 days after proposal receipt

- Grant award or renewal start date: 90 to 135 days after proposal selection

- Further information:

  Specific science program elements: Discipline Scientist listed for each program element in Appendices B-G.

  General NRA policies and procedures:

  Dr. Bradley Carpenter
  Physical Sciences Division
  Code UG
  NASA Headquarters
  Washington, DC 20546-0001
  Telephone: 202-358-0826
  Fax: 202-358-3091
  E-mail: bcarpent@hq.nasa.gov

Your interest and cooperation in responding to this Physical Sciences Division NRA are appreciated. Comments about the inclusive nature and/or structure of this NRA for the OBPR/PSD supporting research and analysis programs are welcome and may be directed to either the Discipline Scientists identified for each program element in Appendices B-G or to the point of contact for General NRA Procedures identified above.

Kathie L. Olsen, Ph.D.
Acting Associate Administrator
Office of Biological and Physical Research

TABLE 1

SCIENCE PROGRAM ELEMENTS SOLICITED IN NRA 01-OBPR-08
(in order of the proposal due dates)

NRA Appendix	Science Program Element	NOI Due Date	Proposal Due Date	Point of Contact Information
C	Combustion Science	2/05/02	3/22/02	Dr. Merrill King Telephone: 202-358-0817 E-Mail: merrill.king@hq.nasa.gov
E	Fundamental Physics	2/26/02	4/12/02	Dr. Mark C. Lee Telephone: 202-358-0816 E-Mail: mark.lee@hq.nasa.gov
F	Materials Science	4/15/02	6/03/02	Dr. Michael J. Wargo Telephone: 202-358-0822 E-Mail: mwargo@hq.nasa.gov
B	Biotechnology	7/15/02	9/03/02	Dr. Stephen C. Davison Telephone: 202-358-0647 E-Mail: sdavison@hq.nasa.gov
G	Special Focus Theme: Materials Science for Advanced Space Propulsion	7/15/02	9/03/02	Dr. Michael J. Wargo Telephone: 202-358-0822 E-Mail: mwargo@hq.nasa.gov
D	Fluid Physics	10/15/02	12/02/02	Dr. Gerald Pitalo Telephone: 202-358-0827 E-Mail: gpitalo@hq.nasa.gov

APPENDIX A
NRA 01-OBPR-08

SYS-EYFUS

This Appendix is to inform you of the change underway at NASA Headquarters in the processing of solicitations and proposals and to provide guidance for using the new system. NASA Headquarters has recently consolidated all of its Peer Review activities under one contract, and as part of this consolidation will now be using a single Internet proposal web site called **SYS-EYFUS** for electronic transmission of all Notices of Intent (NOI), proposal cover pages, and proposal reviewer evaluations. Information pertaining to all Office of Biological and Physical Research (OBPR) solicitations released after June 1, 2001 will be located at http://research.hq.nasa.gov/code_u/code_u.cfm

I. Registering Onto the SYS-EYFUS System

In order to include the names of the Principal Investigator (PI) and Co-Investigators (Co-Is) in these web-based forms, the names must be in SYS-EYFUS as registered users. Therefore, it is necessary for you to add your name to the database to be able to submit any of the electronic forms. If your name is already in the database, it is necessary for you to update your personal information, as additional information is required for names converted to SYS-EYFUS from other databases to make them valid.

It is recommended that you add your name or update your personal information in SYS-EYFUS today, and that you encourage your colleagues to also add or update their information. Waiting until the proposal submission deadline to add or update names to the database may cause a delay in submitting forms electronically.

The SYS-EYFUS database can be accessed at http://proposals.hq.nasa.gov.

1. Click the hyperlink for New User, which will take you to the Personal Information Search Page;
2. Enter your first and last name. SYS-EYFUS will search for your record information in SYS-EYFUS;
3. All records with first and last name entered will be displayed. Choose the correct record, select Continue, and a user ID and password will be e-mailed to you; or
4. Choose None of the Above, select Continue, and a New User Form will be displayed for you to enter your personal information;
5. If no records are found, select Add Record and the New User Form will be displayed;
6. Follow the online instructions and prompts to submit your personal information and a user ID and password will be e-mailed to you.

(NOTE: If your personal record is found but does not have an e-mail address, you will get an error message when you choose it and select Continue. Contact the Help Desk for further instructions.)

With your user ID and password, you can enter SYS-EYFUS by selecting the hyperlink Login on the SYS-EYFUS homepage. Please add or update your information in SYS-EYFUS, especially your mailing address, area of interest, and area of expertise.

Please contact the Help Desk at proposals@hq.nasa.gov or at 202-479-9376 for any assistance or problems with this process.

II. Information on Use of SYS-EYFUS For Preparation and Electronic Submission of a Notice of Intent and of Proposal Forms

NASA utilizes an electronic, Internet-based system of collecting Notice of Intent (NOI) and Proposal submission information for all proposals submitted in response to all types of NASA Research Announcements. The following instructions describe the process in greater detail.

SYS-EYFUS Homepage**:** http://proposals.hq.nasa.gov

A username and a password is required to submit a NOI or proposal information through http://proposals.hq.nasa.gov

To check whether you are already in the system, please go to http://proposals.hq.nasa.gov/forgotpassword/forgotlogin.cfm and type in your first and last name to search our database.

- If you see your name listed in the result set, please select the appropriate radio button and click on continue. This will trigger the system to send an automatic email message with your username and password to your email address listed in our database.

- If your name does not show up on the result set, please choose the radio button named None of the Above and click on continue. This will allow you to add yourself as a NEW USER to the system. The system will prompt you to choose a username and a password towards the end of the new user addition procedure. This username and password combination allows you to access the system and submit NOIs and Proposal Summaries.

If you have a username and password for the SYS-EYFUS system:

A. How to submit a Notice of Intent (NOI):

- Visit http://proposals.hq.nasa.gov/
- On the left hand side, in the Proposal Links Section, click on Login
- Input your username and password and click on Continue
- To submit a Notice of Intent click on New Notice of Intent option from the Options screen, and the Division Specific Opportunities screen will appear.
- In the selection window: highlight **Physical Sciences** and click on Continue
- Click on **NRA 01-OBPR-08 NASA Research Opportunities in Physical Sciences**, and then click on Continue.
- This will bring you to the Notice of Intent Submission Form
- Fill in all the fields, and select a theme from the pop-up lists. All fields are required.
- Click on Submit NOI Page.
- Next is the Team Member Page screen, where you can add or remove team members.

1. Please add any Co-Investigators (COIs). To add a COI, highlight the COI option on the selection list and type in first and last name and click on search. When the resulting set appears, choose the appropriate radio button and click on Add to add the COI to this NOI. After you are done, click on Continue. If the team member is not listed in our database, please have them add themselves as a new user to the system.

2. Please add any other participating organizations (i.e., use of specific facilities, etc.). An individual point of contact must be chosen for each of these participating organizations. To add a participating organization point of contact, highlight the Collaborator Option and proceed as described in 1.

You can repeat these processes to add multiple team members.

- Click on Resubmit NOI Page
- Then click on the Continue button

B. <u>How to submit Proposal Form Information</u>:

- Visit http://proposals.hq.nasa.gov/
- On the left hand side, in the Proposal Links Section, click on Login
- Input your user ID and password and click on Continue
- To submit a New Proposal Summary, click New Proposal Cover Page option from the SYS-EYFUS Options screen, and the New Proposals Cover Page screen will appear.
- Click on New Proposal Cover Page option, and the Division Specific Opportunities screen will appear.
- In the selection window, highlight **Physical Sciences** and click on Continue
- Click on **NRA 01-OBPR-08 NASA Research Opportunities in Physical Sciences**, and then click on Continue.
- This will bring you to the Proposal Cover Page Form
- Fill in all the fields, and select a theme from the pop-up lists. All fields are required.
- Click Continue. Next is the Team Member Page screen, where you can add or remove a team member. "Authorizing Official" and "Contact in case of award" are required to be added to the list. Please add any CO-Is or points of contact from other participating organizations (the latter should be added under the ROLE Collaborator). To add a team member: Highlight the Team Member ROLE on the selection list and type in first and last name; click on Search. When the result set appear, choose the appropriate radio button and click on Add to add the team member to this proposal. You can repeat this process to add multiple team members. After you are done, click on Continue. If the team member is not listed in our database, please have them add themselves as a new user to the system.
- Next is the Proposal Options Page.
- Please fill out the budget form by clicking on the Budget button, filling in project costs, and clicking Continue. This will bring you to the Proposal Budget Review Page. Click Continue if the information is correct.
- At the next screen, click the **Show/Print** button.
- At the Page entitled **Proposal Information Item List** click **Show** to preview your **Proposal Cover Page**. Print the cover page once you have reviewed the information. The cover page must be signed by both the Principal Investigator and the Authorizing Official and attached to the front of your proposal before submission of hard copies to NASA.

- **One (1) signed original and fifteen (15) copies of the proposal should be submitted to NASA by 4:30 p.m. of the due date for the discipline of interest.**

APPENDIX B
NRA 01-OBPR-08

CELLULAR AND MACROMOLECULAR BIOTECHNOLOGY

I. INTRODUCTION

NASA's biotechnology program includes both cellular and macromolecular biotechnology including research on tissue engineering and challenging structural biology problems, respectively. This NRA solicits research to establish the scientific foundations for future experiments on the International Space Station and to support the development of biotechnology applications to long-duration space flight. The program seeks a coordinated research effort involving both space and ground-based research through the solicitation of experimental studies that require the space environment and ground-based studies that will lead to the definition of potential flight experiments or lead to development of new technologies for future NASA missions.

<u>The scope of this research announcement does not include research dealing with the response of living organisms to weightlessness, an area which is the focus of ongoing programs in Fundamental Space Biology and Bioastronautics Research Divisions</u>.

NASA has as a major goal contributing significantly to the opening of the space frontier and expanding the human experience. The focus of the Office of Biological and Physical Research is to foster fundamental understanding of physical, chemical, and biological processes, building a foundation of knowledge that can be applied to Earth- and space-based technologies. Specifically, understanding of the fundamental role of gravity in the space environment in these processes is needed to achieve breakthroughs in science, and to develop enabling technology for exploration of space. The need for improved understanding of biotechnology phenomena and development of new technologies to enable future space technologies and operations should be recognized as one of the opportunities of the discipline.

While basic research is still of major importance to our program, there is a shift of emphasis toward mission-oriented research, that is, research aimed at specific problems in biotechnology for space exploration as well as for Earth-based applications. Thus, it is important that firmer links be developed between the research in support of the exploration of space and practical applications on Earth.

II. PROGRAM RATIONALE

Biotechnology research and development promotes economic competitiveness.

Biotechnology has as its central mission the development of novel biological solutions for the public health, agriculture, and many other important economic areas. There is also abundant practical motivation for advancing biotechnology so that it can contribute to the bioterrorism challenges of the Nation. Advances in biotechnology will benefit a wide range of applications and research areas which depend on biotechnology as a basis for their work. For example, the emerging area of tissue engineering may help the many Americans that suffer tissue damage or organ failure from diseases and accidents every year. With the yearly cost of treating these patients in the billions of dollars, tissue engineering research may allow medical treatments for many of these injures without the complexity of finding tissue and organ donors. In addition, tissue engineering research may also contribute to the understanding of dangerous pathogens and support the development of vaccines against these pathogens. In the pharmaceutical industry, structural biology leads to both fundamental understanding of life processes and in the design of new treatments for disease. Many new drugs and improvements to existing drugs would never make it to the patient if it were not for the molecular analysis of the proteins they target.

With the understanding of how the low gravity environment of space affects biotechnological processes, researchers can develop new science and technology to ensure National leadership in space experiments and Earth applications.

Use of the microgravity environment is just beginning to increase our understanding of the biological sciences and to enable us to develop innovative biotechnological processes that can exploit space. Expansion of biological technologies requires an understanding of the fundamental processes on which these technologies are based. NASA is currently defining a program that will study those processes that are affected by buoyancy driven convection and sedimentation, and that can be gainfully studied using the low-gravity (diffusion controlled transport) environment of space. Gravity's effect on these processes can be virtually eliminated in space, thus allowing space-based experiments, coupled with ground-based experimental and theoretical research, to provide insights into biotechnological processes. NASA's goals are to exploit the unique environment of space to advance the scientific understanding of biotechnology processes, use the scientific knowledge gained through space experimentation on a wide range of biotechnology applications, contribute to Earth-based systems concerned with biotechnology, and develop technologies specifically supporting NASA activities.

Biotechnology can contribute significantly to human space exploration by providing technological advances for biomedical research, life support, and biological research.

NASA has as a major goal contributing significantly to the opening of the space frontier and expanding the human experience. For this to occur, new technologies are required for studying and maintaining astronaut health and associated life support systems. Biotechnology can contribute significantly to human space exploration by providing technological advances for biomedical research, life support, and biological research. For example, development of tissue models that enable the study of space induced diseases including bone loss, muscle atrophy, and radiation damage can help minimize the use of animals in space research. Biotechnology can also be used to reduce NASA mission requirements such as weight, volume, electrical power, etc. In addition, these systems may be able to be produced and function very reliably and economically because biological systems are capable of functioning in a highly reproducible manner, far more reproducible than any corresponding industrial processes. To make this approach a reality, the fundamental role of gravity in biotechnological processes needs to be studied to achieve breakthroughs in science, and to develop enabling technology for exploration of space. The need for improved understanding of biotechnology phenomena and development of new technologies to enable future space technologies and operations are central to NASA's mission.

III. CURRENT PROGRAM CONTENT

At this time, NASA is supporting approximately 100 investigations under the biotechnology program in the following areas:

TISSUE ENGINEERING

NASA has developed low-shear bioreactor technology and uses the low gravity environment of space to provide a unique three-dimensional cell culture setting that addresses applied and fundamental cell science challenges associated with tissue engineering. Ground-based research studies demonstrate that both normal and neoplastic cells and tissues recreate many of the characteristics in the NASA bioreactor that they display *in vivo*. Generations of the appropriate cytoarchitecture and inherent tissue function have occurred in the engineering of cartilage, cardiac muscle, kidney, and other tissues using the NASA bioreactor technology. In addition, the space environment affords a unique opportunity to culture cells because they may be grown in an extremely low shear environment without sedimentation. This provides the setting to readily assemble cells and recreate the three-dimensional relationships among cells that are extremely important to normal tissue morphogenesis and thereafter, organ function. Results reported on long-duration tissue engineering experiments on Mir validated tissue morphogenesis in space and demonstrated unique characteristics of tissue produced in the microgravity environment of space. The cell science component of this program is directed at understanding the role of reduced hydrodynamic stress and microgravity on mammalian cell adhesion, proliferation, and eventual differentiation. Research areas included under this subtopic are as follows:

- Development of tissue models that support biomedical research in space and on Earth including models for bone loss, muscle atrophy, and radiation risks
- Engineered tissue platforms for drug testing and biopharmaceutical production
- Research to assess the value of low shear culturing and tissue engineering using rotating wall vessels
- Use of the microgravity environment of space to surmount obstacles to the propagation of complex tissues
- Development of functional and differentiated tissues for use in transplantation

BIOREACTOR DESIGN AND TECHNOLOGIES FOR TISSUE ENGINEERING

A recent NRC report (see bibliography) has recommended that NASA support the development of new technologies such as miniaturized culture systems and compact analytical devices that enhance ISS biotechnology experiments in cell science and tissue engineering. Therefore, research to address these NRC recommendations is solicited in this NRA.

The physical environment that cells and tissue are cultured in has a dramatic effect on the differentiation of the cells and the resulting tissue cytoarchitecture. NASA is coupling fluid physics, biomaterials, and automated control systems into its tissue engineering program with the goal of generating novel bioreactor designs with enhanced transport and appropriate fluid shear properties to support the growth of complex tissue constructs. Research areas included under this subtopic are as follows:

- Miniaturized culture systems for cell science and tissue engineering research

- Compact analytical devices that support ISS research activities in cell science and tissue engineering

- Research into new tissue culture technologies and approaches that support three-dimensional tissue propagation (for example, perfusion or pulsed-flow methods)

- Research on fluid modeling and the effect of reduced levels of hydrodynamic shear and the role of mass transport on cellular propagation and tissue assembly in rotating wall bioreactor systems

- Research to support the development of technologies (biosensors for pH, glucose, and oxygen levels, etc.) and maintenance strategies for three-dimensional tissue culture to allow long-term automation and improve the tissue culturing process via a more physiologically balanced system

- Biomaterials and scaffolds for tissue engineering: biopolymer and biomaterials research that support growth of anchorage dependent cells and allows tissue to form with the correct morphology

STUDIES ON CHANGES IN CELLULAR FUNCTION

Gene array analysis of cultured human renal cells was used to do the first comprehensive analysis of the microgravity induced adaptive responses as demonstrated in the expression of 10,000 genes. In this case, more than 1,600 genes in the kidney cells changed their expression levels up and down in microgravity, demonstrating that there is a select group of gravity dependent genes. Renal cells were grown in microgravity, on the ground using the rotating wall vessel culture system, and in a centrifuge at 3g. While only 5 genes changed more than 300% during 3g centrifugation, 1,632 genes changed in microgravity, and 914 genes changed in the rotating wall vessel. Thus, renal cells display discrete responses to changes in their gravitational environment during growth. Research in this area will demonstrate the use of space as a potential probe to discover new cellular regulatory systems and reactions. Such discoveries can open new strategies in understanding disease processes and advance our knowledge of cellular processes necessary for invoking low gravity research and technologies to support basic and applied science goals. Research areas included under this subtopic are as follows:

- Studies on gene expression
- Research into metabolic adaptations
- Cytoarchitecture studies including membrane composition and cytoskeletal array

RESEARCH ON CHALLENGING STRUCTURAL BIOLOGY PROBLEMS

A recent NRC report (see bibliography) has recommended that NASA fund a series of grants to support research that uses microgravity to produce crystals of macromolecular assemblies with important implications for cutting-edge biology problems. The NRC report stated that the success or failure of these research efforts would definitively resolve the issue of whether the microgravity environment can be a valuable tool for structural biology.

Therefore, requests for structural biology research proposals that address the NRC report recommendations are solicited in this NRA. Some examples of classes of systems that currently meet these criteria include the following: membrane proteins, molecular motors, and biopolymer synthetic machinery (e.g., origin of replication complexes and transcriptional pre-initiation complexes). The NRC report described all of these systems as elaborate and fragile, which makes them difficult to crystallize unless the conditions are just right; microgravity might improve the quality of the crystals enough to increase the resolution to a level at which key structures can be discerned. For example, macromolecular assemblies that have been resolved to approximately 4 angstroms could benefit if microgravity crystallization allowed improvement to 3.5 Angstroms, where alpha helices and beta sheets could be more accurately discerned.

Challenging structural biology problems where efforts are already underway, although crystallization has been difficult, would be favored over nascent research projects in this area.

Research areas included under this subtopic are as follows:

- Extending crystallographic analyses to more complex and challenging systems, such as motor proteins, glycoproteins, and integral membrane proteins by using the space environment
- Elucidation of the fundamental factors that provide for the observed benefits in diffraction performance when macromolecular crystals are grown in microgravity
- Use of the microgravity environment of space to support neutron diffraction studies by growing larger, high quality crystals on the order of millimeters
- Development of technologies to improve macromolecular crystallization throughput for ISS structural biology and proteomics research
- Technologies for monitoring, controlling, and automating crystal growth of biological macromolecules to accelerate progress in structural biology

- Research on macromolecular crystal growth mechanisms, defect formation, and optimization strategies as it relates to challenging systems in structural biology

BIOLOGICAL NANOTECHNOLOGY AND BIOMATERIALS

NASA is looking to expand its current activities in protein-based materials for application to future NASA missions. Biological nanotechnology and biomaterials can be used to reduce NASA mission requirements such as weight, volume, electrical power, etc. Biological molecules can be incorporated into nanotechnology development in several ways: biological molecules or assemblies could serve as molecular-sized sensors, genetic engineering could be used to produce a single molecule with both a molecular receptor and a signal function, etc. Research on structural proteins such as collagen, keratin, and silk may form the basis for producing a variety of hierarchical structures that are characterized by the ability to undergo biomolecular self-assembling. Structural protein-based materials may be able to incorporate novel properties by genetically engineering the sequences or incorporating modular components from other proteins. Finally, these systems may be able to be produced very reliably and economically because biological systems are capable of manufacturing large molecules in a highly reproducible manner, far more reproducible than any corresponding industrial processes. Research areas included under this subtopic are as follows:

- Development of engineered biological systems that can be exploited for applications such as ultrafiltration membranes or solid enzyme catalysts
- Research on the fabrication of complex, self-assembling protein devices and materials for NASA applications
- Research on structural protein-based materials that incorporate novel properties for use in NASA activities

IV. FUTURE DIRECTIONS OF THE PROGRAM

Future proposals are not limited to the topic areas discussed in this Appendix; extension to biotechnology topics not currently included in NASA's Biotechnology Program is strongly encouraged to permit us to broaden the program scope. Research areas that have been identified as having potential to contribute to human exploration of space include the following:

SEPARATION, PURIFICATION, AND REMEDIATION METHODS

Separation and purification methods to clean and recycle water are technologies needed to reduce the costs of exploration in long-duration space flight research. For example, cell and tissue systems require significant amounts of pure water for long-duration space studies. Purification methods must be specific for toxic molecules, reliable, inexpensive, and make small demands on spacecraft resources such as power, mass, and volume. Remediation of fluids is an important enabling technology for spaceflight. One possible biological application is the use of cellular organisms or biological molecules to convert or catalyze fluid waste to usable products, such as potable water, oxygen, methane, etc.

SELECTIVE PRESSURES ON CELL POPULATIONS

Critical for humanity's long-term occupation of space is the assessment of selective pressures on mammalian and microbial cell populations. The induced phenotypic and genotypic changes need to be assessed through generations of cell populations sustained in the space environment (low gravity, etc.). The development of unique technologies and methodologies to enhance research on selective pressures will apprise us of the risks to our biological integrity and to our life-based support systems.

DEVELOPMENT OF BIOSENTINEL TECHNOLOGIES

Genome damage from radiation is one primary source of DNA mutation. NASA is seeking new technologies to monitor mutation levels in DNA. Biosensor and biosentinel systems to monitor radiation effects and other space environmental factors (magnetic fields, atmospheres, gravitational fields, etc.) on cell replication and DNA for manned and unmanned robotic science missions are needed. These biosentinel systems for exploratory research may incorporate biomolecules in their detection systems. DNA biosentinel technology will be important for future exploration of space by humans.

MICROBIOSENSOR MONITORING DEVICES

Micro- and Nano-technology based sensors for use in biological systems and experiments may have unique application to long-duration space missions. The development of extremely stable and small biosensor devices is central to advancement of many biotechnological processes and their use in support of long-duration space missions.

APPLICATION OF EXTREMOPHILIC ENZYMES

Certain bacteria and archeabacteria have been found to flourish in extreme environments: high and low temperatures, high and low pH, etc. The unique and robust enzymes produced by these organisms, or the organisms themselves, can have applications in industry and may be of substantial benefit for certain chemical processes involved in long duration space flight or colonization of the Moon and Mars. The specificity of enzymes is superior to conventional catalysts and can serve to eliminate multi-step reactions and unwanted side products, making the overall chemical process much more efficient. Research may establish unique application of extremophiles or their enzymes in support of exploration goals.

IN SITU RESOURCE UTILIZATION EMPLOYING BIOLOGICAL TECHNOLOGIES

The phrase *in situ resource utilization* has been used to describe the utilization of ores or soils of foreign planets, moons, or asteroids for the production of materials needed for space exploration. Identification or engineering of cells or molecules with the potential to catalyze the production of materials such as oxygen, hydrogen, methane, etc. using alien materials is of interest. Biologically based catalysts are of particular interest since they can be efficient and effective at moderate and low temperatures that are often impractical for standard industrial processes. Biological molecules can be genetically engineered and expressed for the purposes of isolating particular compounds or metals from soil.

GENETIC ENGINEERING OF BIOMOLECULES FOR LONG-TERM SPACE FLIGHT

Cells and subcomponents of cells are efficient chemical plants reproducibly manufacturing numerous, large, and multifunctional compounds. Genetic engineering allows the manipulation of cells to produce these compounds of specific interest. In most cases, this production is difficult or impossible by standard organic chemistry. Cells such as *Escherichia coli*, yeast, etc. can be engineered to produce one or more compounds. Possible uses for genetically engineered proteins would be nutrients and medicines of value for spacefarers, or a protein-based artificial blood for emergency situations. Ideally, genetically engineered cells would be stored in an inactive state. When needed, the cells could be cultured and the required material expressed.

BIOMEDICAL APPLICATIONS OF NASA RESEARCH

NASA research and technology supported under the Physical Sciences Division may have unique application in certain areas of biomedical research that would be of substantial benefit and accelerate a particular area. Under this solicitation, NASA is looking to support investigations that may be collaborative with other agencies in which NASA research or technology is being applied to a particular biomedical research problem. For example, NASA-developed laser light scattering technology has found application in biomedical research on eye diseases. Related areas in which

NASA is conducting biomedical related research include the Biomedical Research and Countermeasures Program, and its collaborative efforts with the National Space Biomedical Research Institute, and the Biomolecular Physics and Chemistry Program and its collaborative efforts with the National Cancer Institute. Additional information on these programs is available, respectively, at these websites http://spaceresearch.nasa.gov/research_projects/biomedical.html and http://spaceresearch.nasa.gov/research_projects/biomolecular.html .

METABOLIC ENGINEERING

Metabolic Engineering (ME) is the targeted and purposeful alteration of metabolic pathways found in an organism to better understand and use cellular pathways for chemical transformation, energy transduction, and supramolecular assembly. ME typically involves the redirection of cellular activities by the rearrangement of the enzymatic, transport, and regulatory functions of the cell through the use of recombinant DNA and other techniques. ME has many potential applications for NASA long-duration missions where production increased efficiency of complex biomolecules is required. Proposals are invited that develop enabling technologies or potentially useful strategies for employing ME on future NASA missions.

V. INTERDISCIPLINARY RESEARCH PROJECTS

To accomplish biotechnology goals, this research announcement is also soliciting interdisciplinary proposals that encourage the formation of teams of researchers that can advance research and develop novel approaches through an interdisciplinary approach. Research groups from the same or different institutions may team and submit a joint research proposal. Proposals in this category must be formed through a cooperative arrangement between the research groups with one research group having, for example, comprehensive bioengineering and fluid dynamic capabilities, and the other an outstanding background in the biological sciences. The goals of the interdisciplinary research projects are to develop advanced technology, promote ground-breaking research, and support technology transfer. Because biotechnology is an inherently cross-disciplinary activity, interdisciplinary proposals are being solicited under this announcement to produce research teams with a critical size to accelerate areas of interest to NASA and address complex research problems.

Interdisciplinary proposals should identify key personnel and their expertise. It must be clearly stated who the Principal Investigator and the lead institution are and how the effort will be integrated. A science team, for example, may wish to work with a strong engineering team, at its own or another institution, but these proposals should state how teaming and cooperation between the engineering and science teams will be managed. Management structure, goals, and cooperation with the research community to facilitate the transfer of technology must be evident in the proposal.

VI. HARDWARE AND FACILITY DESCRIPTIONS

NASA is pursuing a program for the development of payloads capable of accommodating multiple users and their science requirements. In the interest of minimizing project cost and complexity, NASA encourages the use of existing U.S. or Internationally developed space hardware whenever consistent with experiment requirements.

A list of the flight hardware available or planned for use in the Cellular and Macromolecular Biotechnology Program is given below. Detailed descriptions of this hardware can be obtained at the following Web sites:

Cellular Biotechnology: www.jsc.nasa.gov/sa/bso.html
Macromolecular Biotechnology: www.crystal.nasa.gov

International equipment described here may be offered for flight on a cooperative basis with agencies from various countries. The availability of the hardware described in this section is contingent upon the availability of funds, flight manifest opportunities, and, for international hardware, cooperative agreements between NASA and the appropriate foreign space agency.

A. ISS GLOVEBOX (MGBX) (NASA/MSFC)

B. THERMAL ENCLOSURES

Use of the Single-locker Thermal Enclosure System (STES) or the Thermal Enclosure System (TES) is encouraged for investigations requiring experiment temperature control.

1. Single Locker Thermal Enclosure System (STES)
2. Thermal Enclosure System (TES)
3. Space Station Thermal Enclosure Systems

C. MACROMOLECULAR BIOTECHNOLOGY

1. Protein Crystallization Apparatus for Microgravity (PCAM)
2. Diffusion-controlled Protein Crystallization Apparatus for Microgravity (DCAM)
3. Protein Crystallization Facility - Light Scattering Temperature (PCF-LST)
4. Protein Crystallization Facility - Variable Gradient (PCF-VG)
5. Protein Crystallization Diagnostics Facility (PCDF) (European Space Agency/ESA)
6. Interferometer for Protein Crystal Growth (IPCG)
7. Dynamically Controlled - Protein Crystal Growth (DC-PCG)
8. Observable Protein Crystal Growth Apparatus (OPCGA)

D. CELLULAR BIOTECHNOLOGY

The Cellular Biotechnology flight hardware provides the technological capability for addressing the potential of microgravity as a tool in tissue engineering and cell science.

1. Slow Turning Lateral Vessel (STLV)
2. High Aspect Ratio Vessel (HARV)
3. The Hydrodynamic Focusing Bioreactor (HFB)
4. The Rotating Wall Perfused Vessel (RWPV)
5. The Biotechnology Specimen Temperature Controller (BSTC)
6. The Biotechnology Refrigerator (BTR)
7. Cryodewar
9. The Cell Culture Unit (CCU) Ames Research Center

E. OTHER BIOTECHNOLOGY FLIGHT HARDWARE

1. Commercial Generic Bioprocessing Apparatus (CGBA)
   a) Fluid Processing Apparatus (FPA)
   b) Group Activation Pack (GAP)
   c) GBA-INC
   d) GBA-ICM

2. ADvanced SEParations (ADSEP)

3. Materials Dispersion Apparatus (MDA) Minilab

VII. NRA FUNDING AND SCHEDULE

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 p.m. EDT). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below.

Notice of Intent Due:	July 15, 2002
Proposal Due:	September 3, 2002
Final Selections:	March 2003
Funding Commences:	No sooner than April 2003

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA. For the purposes of budget planning in the Cellular and Macromolecular Biotechnology Program, we have assumed that 3 highly meritorious flight experiment definition proposals will be funded. These efforts are typically funded at an average of $200,000 per year. It is also anticipated that approximately 16 ground-based investigations from those judged to be highly meritorious will be funded, at an average of approximately $170,000 per year, for up to 4 years. In addition, it is expected that two interdisciplinary projects which meet the demanding scientific merit and programmatic standards will be funded at an average cost of approximately $600,000 per year.

The initial fiscal year funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts.

VIII. BIBLIOGRAPHY

The *Microgravity Science and Applications Program Tasks and Bibliography for FY 2000*, which contains a searchable database on currently funded research, may provide useful information to investigators and can be viewed at the following Web site:
http://peer1.nasaprs.com/peer_review/taskbook/micro/mg00/mtb.cfm

NRC Report on *Future Biotechnology Research on the International Space Station* is available at the following Web site: www.nationalacademies.org/ssb/btfmenu.htm

Questions about this program element may be directed to the Biotechnology Enterprise Scientist:

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APPENDIX C
NRA 01-OBPR-08

MICROGRAVITY COMBUSTION SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

NASA has supported research in Microgravity Combustion Science for over two decades. This extensive research program supports theoretical and experimental investigations in ground-based laboratories. Also, many investigations are conducted using equipment built to take advantage of the limited low gravity test times available in ground-based facilities, such as the drop-towers at the NASA Glenn Research Center or NASA's Parabolic Low Gravity Flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on combustion processes and phenomena, providing the necessary frameworks for development of rigorous understanding of basic combustion phenomena. This research can eventually mature to the point where it becomes the focus of a well-defined flight experiment, utilizing sounding rockets, Space Shuttle flights, and International Space Station (ISS) facilities.

The need for improved understanding of combustion phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. Included are development of spacecraft combustion/propulsion systems, fire safety, use of in-situ resources, and power generation in extraterrestrial environments. In the area of spacecraft fire safety, better characterization of flammability of various materials, improved fire detection, and improved fire suppression under microgravity conditions are of importance. At a Spacecraft Fire Safety Workshop held in June 2001, a number of experts in various disciplines related to spacecraft fire safety were brought together to 1) identify research needed to ensure fire safety in future Shuttle and International Space Station systems and payloads, 2) promote ISS fire safety through proposals for innovative designs, operations, and validation procedures, 3) identify areas of concern related to fire safety inherent to long-duration space missions in Earth orbit and beyond, and 4) anticipate research required to plan and design habitats for planetary exploration. Further details on this workshop and its products may be found on the Web at http://www.ncmr.org/events/firesafety.

While basic research into fundamentals is still considered to be of major importance to our program, there has recently been a major shift of emphasis toward “mission-oriented” research; that is, research aimed at specific problems in combustion applications on Earth as well as under reduced gravity or microgravity conditions. Thus, it is important that firmer linkages between the research being done using microgravity and applications to practical applications on Earth (e.g., increased efficiency of conversion of chemical energy contained in fuels to useful work, reduction of combustion-generated pollutants from automobile engines and other combustors, decreased fire and explosion hazards) be established for an increasing percentage of efforts funded under this program.

II. PROGRAM RATIONALE

Combustion processes play a major role in the Nation’s economy, but in so doing result in production of undesired byproducts (pollutants).

Combustion has been a subject of increasingly vigorous scientific research for over a century, not surprising considering that combustion accounts for approximately 85% of the world’s energy production and is a key element of many critical technologies used by contemporary society. For example, electric power production, home heating, surface and air transportation, space propulsion, and materials synthesis all utilize combustion as a source of energy. Yet, although combustion technology is vital to our standard of living, it poses great challenges to maintaining a habitable environment. For example, pollutants, atmospheric change and global warming, unwanted fires and explosions, and the incineration of hazardous wastes are major problem areas that would benefit from improved understanding of combustion. Thus, combustion phenomena have unusually large impacts on major problems facing us today. The United States alone consumes approximately 90 Quadrillion BTU of energy per year, at a cost of approximately $400 billion (assuming $25 per barrel oil). Of this amount, approximately 90% uses combustion processes to generate the desired products of heat or work.

Study of the details of combustion processes is greatly complicated at normal gravity by buoyancy effects; use of microgravity eliminates buoyancy and its associated complications.

Effects of gravitational forces on earth impede combustion studies more than they impede most other areas of science. Combustion intrinsically involves the appearance of high-temperature gases whose low density triggers buoyant motion under normal gravity conditions, vastly complicating the execution and interpretation of experiments. The effects of buoyancy (proportional to gravity level) are so ubiquitous that we often do not appreciate the enormous negative impact that they have had on the rational development of combustion science. Perversely, the effects of buoyancy are strongest in the highest temperature regions of flames, where most of the chemical reactions occur. This causes these reaction zones, where current understanding is most limited, to collapse into very thin sheet-like regions not resolvable by existing or anticipated instrumentation. Buoyant motion also triggers the onset of turbulence, yielding unsteady effects as an additional complication. Finally, buoyancy causes particles and drops to settle, inhibiting studies of heterogeneous flames important to furnace, incineration and power generation technologies. Microgravity offers potential for major gains in combustion science understanding in that it offers unique capability to establish the flow environment rather than having it dominated by uncontrollable (under normal gravity) buoyancy effects, and through this control extend the range of test conditions that can be studied.

With the understanding of fundamental combustion subprocesses that can be obtained from microgravity testing, rational approaches to improved combustor design can be developed.

A major goal of microgravity combustion research is production of fundamental (foundational) knowledge that can be used in developing accurate simulations of complex combustion processes, replacing current “cut-and-try” approaches and allowing developers to improve the efficiency of combustion devices, to reduce the production of harmful emissions (estimated to cause in excess of 50,000 deaths per year), and to reduce the incidence of accidental uncontrolled combustion (fires, explosions) which cause in excess of 5,000 deaths, 25,000 injuries, and $25 billion in property losses each year. It appears that the most fruitful approach to achieving meaningful technology gains in processes involving combustion is to concentrate on developing better understanding of the fundamentals of the individual processes involved. With full understanding of the physics and chemistry involved in a given combustion process, including details of unit processes and their interactions, physically accurate models for use in parametric exploration of new combustion domains via computer simulation can be developed, with possible resultant definition of radically different approaches to accomplishment of various combustion goals.

Differences in combustion processes under microgravity conditions must be addressed and quantified in order to maximize fire safety on orbiting vehicles such as the International Space Station.

Fire and/or explosion events aboard spacecraft could be devastating to international efforts to expand the human presence in space. Accordingly, NASA seeks to improve fire safety aboard spacecraft such as the Shuttle and the International Space Station. Testing to date has shown that ignition and flame spread on fuel surfaces (e.g., paper, wire insulation) behave quite differently under partial gravity and microgravity conditions. In addition, fire signatures—i.e., heat release, smoke production, flame visibility, and radiation—are now known to be quite different in reduced gravity environments; this research has provided data to improve the effectiveness of fire prevention practices, smoke and fire detectors, and fire extinguishment systems. The more we can apply our scientific and technological understanding to potential fire behavior in microgravity and partial gravity, the more assurance can be given to those people whose lives depend on the environment aboard spacecraft or eventually on habitats on the Moon or Mars.

The value of microgravity combustion research is shown by definition of desirable results, identification of key barriers to achieving them, and demonstration of how microgravity research overcomes these barriers.

One approach to defining the value of the microgravity combustion program is through definition of desirable benefits, identification of key scientific barriers to achievement of such benefits, and discussion of how microgravity studies can be utilized to overcome these barriers. One goal of combustion research is reduction of combustion-generated pollutants that pollute the atmosphere and lead to global warming. Barriers to progress in this area include lack of understanding of reaction, pyrolysis, and devolatilization kinetics, of soot nucleation, growth, and oxidation processes, of flame stabilization mechanisms, and of kinetic-transport interactions; microgravity research can contribute to overcoming these barriers by providing increased spatial resolution through use of larger length scales that cannot be achieved at normal gravity without confounding buoyancy effects. Another potential benefit of combustion research is reduction of fire and explosion hazards. Technological barriers here include lack of understanding of flammability limit mechanisms, ignition limit mechanisms, smolder-to-fire transition, and fire growth processes; microgravity studies can contribute significantly by elimination of the intrusion of buoyancy effects that obscure these fundamental phenomena under normal gravity conditions. A third goal is development of improved hazardous waste incineration processes, currently hindered by lack of understanding of reaction pathways leading to pollutants and toxic products; microgravity can help by providing improved spatial resolution, long controllable residence times, and elimination of settling of condensed phase species. Still another objective is development of increased efficiency of conversion of chemical energy stored in fuels to useful heat and work; progress is hampered at normal gravity by lack of understanding of soot production processes, turbulence-flame interactions, droplet vaporization, near-critical behavior, and very fuel-lean combustion. Microgravity is useful here in providing controllable residence times, reducing of turbulence scales to allow direct model comparison, providing truly one-dimensional geometries (allowing meaningful comparison of tractable models with data), and general simplification of experiments. Production of improved materials via combustion synthesis is an important development area today; barriers to progress include lack of understanding of heterogeneous kinetics and of processes leading to improved structural ordering and infiltration of materials in composites; a microgravity environment can help here by eliminating sedimentation (which leads to particle agglomeration) and by eliminating gravity-induced flow through pores in the developing structure.

III. CURRENT PROGRAM CONTENT

At this time, we are funding approximately 20 flight and flight definition and 70 ground-based investigations encompassing both experimental and modeling activities. These may be broken out into a number of categories and subcategories (somewhat arbitrarily) as follows:

Gaseous Flames: Diffusion Flames, Premixed Flames, Partially Premixed Flames, Triple Flames, Flame-Vortex Interactions, Kinetics, Electrical Field Effects, Magnetic Field Effects, Flame Suppression, Edge Flames

Droplets, Sprays, Particles, and Dust Clouds: Single Droplets, Droplet Arrays, Sooting Droplets, Sprays, Particle Combustion, Dust Clouds, Bubble Combustion

Combustion Synthesis: Self-Propagating High-Temperature Synthesis (SHS), Fullerene production from Flames, Nanoparticle production from Flames, Agglomerate production from Flames, Plasma Synthesis

Surface Combustion/Fire Safety: Flame Spread, Flammability Testing, Flame Detection, Extinguishment, Smoldering, Liquid Pool Combustion, Secondary Fires

Miscellaneous: Cold Boundary Flames, Diagnostics Development

More information regarding these programs can be obtained from papers presented in the Proceedings the Sixth International Microgravity Combustion Workshop (May 2001), available at http://www.ncmr.org/events/combustion2001/index.html.

IV. FUTURE DIRECTIONS OF THE PROGRAM

As recommended by the Microgravity Combustion Discipline Working group (an external advisory group), we plan to expand this program into additional activities in the years to come, covering a much wider range of reacting flow phenomena. Examples of activities that may be added to the program include

- Chemical Vapor Deposition Processing
- Chemical Vapor Infiltration Processing for Densification of Woven Materials
- Supercritical Water Oxidation
- In-situ (Mars, Moon) Resource Utilization Power Cycles
- In-situ Chemical Processing
- Thermal Plasmas

In addition, we may develop initiatives (clustered programs) in such areas as

1. Active Control of Combustors
2. Very Fuel-lean Combustion, with Emphasis on Hydrogen as a Fuel
3. Advanced Propulsion Systems for Interplanetary Travel
4. Development of Combustion Processes for Production of Fullerenes and Single-Walled Nanotubes

It should be emphasized that future proposals are <u>not</u> limited to the topic areas discussed in this Appendix; <u>extension to combustion topics not currently included in the Microgravity Combustion program is strongly encouraged</u> to permit us to broaden the program scope. As always, it is important that the investigator establish clear microgravity relevance (preferable) <u>or</u> relevance to OBPR space exploration goals, as delineated in the main body of this NRA, of the proposed study.

In selection of future projects, while peer review for determination of technical merit and microgravity relevance will continue to be important in terms of providing a necessary condition for program selection, additional consideration will be given into how these programs fit within a framework developed for achievement of the goals of the discipline. In addition, it is very important that we coordinate our activities with those of other government agencies funding combustion research activities, and that we concentrate on transferring knowledge gained from our research to industrial use.

V. HARDWARE AND FACILITY DESCRIPTIONS

A list of hardware, facilities, and diagnostic capabilities available or planned for use in the Microgravity Combustion program is given below. Detailed descriptions of the facilities and hardware may be found at the following Web site:
http://microgravity.grc.nasa.gov/MSD/MSD_htmls/piinfo.html.

- FLIGHT HARDWARE

The experimental hardware listed in this section is under development for flight on ISS. NASA anticipates additional future flight opportunities for investigations capable of using this hardware. To accommodate as many investigations as possible, the chamber inserts and diagnostics systems are being designed to be as modular as possible. This will allow PIs to share many major systems, reducing cost and time to flight.

A. ISS COMBUSTION INTEGRATED RACK (CIR)

B. MINI-FACILITY INSERTS

1. Multi-User Droplet Combustion Apparatus (MDCA)
2. Multi-User Solid Fuel Apparatus (FEANICS)
3. Multi-User Gaseous Fuels Apparatus (MGFA)

C. ISS MICROGRAVITY SCIENCE GLOVEBOX

D. SOUNDING ROCKETS

- GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the MRD combustion program include two drop towers at NASA's Glenn Research Center (GRC) and a KC-135 aircraft that is based at the Johnson Space Center but may fly 6 campaigns per year from GRC. Each of these facilities and resources has different capabilities and characteristics that should be considered by an investigator to determine which are best suited for conducting combustion science research.

A. 2.2-SECOND DROP TOWER

B. 5.18-SECOND ZERO-GRAVITY FACILITY

C. REDUCED-GRAVITY AIRCRAFT

- DIAGNOSTICS/MEASURING CAPABILITIES

NASA has adapted or developed a large number of diagnostic/measurement techniques for use in the Microgravity Combustion research program, with some of these techniques, including particle imaging velocimetry, laser light scattering, and Rainbow Schlieren Deflectometry, having already been demonstrated in flight. A brief list of techniques, already in use or under development and possibly available for use in future programs, appears below.

1. Soot Temperature Measurements Using Pyrometric Techniques
2. Rainbow Schlieren for Measurement of Temperature Distributions
3. Planar 2D Temperature and CH and OH Concentration Measurements Via Rayleigh Scattering and Laser-Induced Fluorescence
4. Light Sheet Flow Visualization and/or Velocimetry
5. Laser Doppler Velocimetry

6. Liquid Surfaces Temperature and Vapor Phase Concentration Measurements Via Exciplex Fluorescence
7. Determination of CH4, CO2, and H2O Concentrations Via Line Absorption Techniques
8. Planar Laser-Induced Fluorescence for Determination of Flame Front Position
9. Particle Imaging Velocimetry
10. Liquid Phase Thermometry and Fluorescence of Aromatics to Evaluate Droplet Surface Transport and Internal Flow
11. Diode Laser Wavelength Modulation Spectroscopy for Quantitative Molecular Oxygen Concentration Measurements.
12. Compact Laser-Diode CCD Array for Measuring Instantaneous Radial Variations of the Temperature Fields within a Burning Droplet and in the Gas-Phase around it while also Instantaneously Measuring Droplet Size and Regression Rate.
13. Laser-Induced Incandescence for Measurement of Soot Volume Fractions

- RESOURCES REQUESTED FROM NASA (FORM CF)

To aid NASA in evaluating the total annual cost of supporting proposed experimental research to be conducted at the NASA Glenn Research Center, investigators are requested to complete and submit with their proposals a two-page form that can be obtained from http://microgravity.grc.nasa.gov/combustion/piinfo.htm or from the Web site from which you obtained this NRA.

[These two pages will not be counted against the maximum allowable page count for your proposal.]

VI. NASA/NEDO COOPERATIVE ACTIVITIES

NASA has entered into an agreement with the New Energy and Industrial Technology Organization (NEDO) in Japan resulting in establishment of a Microgravity Combustion Coordination Group (MCCG) for identifying areas of potential cooperation related to combustion research in a microgravity environment in which each side might utilize facilities of the other side, primarily NASA's Glenn Research Center facilities and the dropshaft (10 second microgravity duration) of the Japanese Microgravity Center (JAMIC). Possible personnel exchanges and joint utilization of microgravity facilities of both sides for programs proposed jointly by Japanese and U.S. investigators will be reviewed on a case-by-case basis by the MCCG subsequent to acceptance of the proposal via peer review in each country; any specific cooperative activities recommended by the MCCG will be implemented through individual agreements negotiated between NASA and NEDO. Regarding this solicitation (NRA), U.S. investigators may include such cooperative activity as part of their proposal. However, since participation by the Japanese investigators will depend on their being funded by their own sponsoring agencies via a separate review process, it is recommended that the proposal be structured so as to permit accomplishment of significant defined goals without the participation of the Japanese investigator(s). For further information/clarification, potential investigators should contact Dr. Merrill K. King at 202-358-0817.

VII. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

Please note that we plan to issue NRAs annually instead of biennially as in the past: since the total budget for microgravity combustion research will remain approximately constant, we will be making less awards for each NRA. Accordingly, for the purposes of budget planning, we have assumed that the Physical Sciences Division will, in the combustion area, fund approximately 25 ground-based projects from those judged to be highly meritorious (at an average of about $120,000 per year) for up to 4 years. At this time, due to severe resource limitations, we do not plan to make flight definition awards in the combustion area from this NRA. The initial fiscal year (FY) 2003 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRA's similar to this NRA will be issued annually, and it is planned that funds will be available for additional investigations.

A complete schedule for the receipt and review of proposals to the Microgravity Combustion Science program follows:

Letter of Intent Due: February 5, 2002

Proposal Due: March 22, 2002

Final Selections: September 2002

Funding Commences: No sooner than October 2002
(dependent upon length of the procurement process)

VIII. BIBLIOGRAPHY

Documents that may provide useful information to investigators are listed below:

Microgravity Science & Applications Program Tasks and Bibliography for FY1998. NASA Technical Memorandum 209007, March 1999.

Microgravity Physical Sciences Division Program Tasks and Bibliography for FY2000. Available at http://peer1.nasaprs.com/peer_review/taskbook/taskbook.html

Microgravity Combustion Science: Progress, Plans, and Opportunities, NASA Technical Memorandum 105410, April 1992.

Microgravity Combustion Science: 1995 Program Update, NASA Technical Memorandum 106858, April 1995.

Microgravity Combustion Research: 1999 Program and Results, R. Friedman, S. Gokoglu, and D. Urban, Microgravity Combustion Science Branch, NASA/TM-1999-209198, June 1999.

Proceedings of the Third International Microgravity Combustion Workshop, NASA Conference Publication 10174, April 11-13, 1995.

Proceedings of the Fourth International Microgravity Combustion Workshop, NASA

Conference Publication 10194, May 19-21, 1997.

Proceedings of the Fifth International Microgravity Combustion Workshop, NASA Conference Publication 1999-208917, May 1999. Also available on the Web at http://www.ncmr.org/events/combustion1999.html

Proceedings of the Sixth International Microgravity Combustion Workshop, NASA Conference Publication 2001-210826, May 2001. Also available on the Web at http://www.ncmr.org/events/combustion2001/index.html

In addition, considerable information on Glenn Research Center facilities, experiments, educational activities, missions, and services are available on the Web at http://microgravity.grc.nasa.gov

Questions about this program element may be directed to the Microgravity Combustion Science Enterprise Scientist:

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APPENDIX D
NRA 01-OBPR-08

FLUID PHYSICS: RESEARCH OPPORTUNITIES

I. INTRODUCTION

NASA has supported research in microgravity fluid physics for over three decades. An extensive research program supports experimental and theoretical investigations in ground-based laboratories. Some investigations are conducted using experiments built for the limited low gravity test times available in ground-based facilities such as the drop-towers or flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on fluid processes and phenomena and represent the bulk of the research program. Ground-based research has also been used to gain a rigorous framework to define experiments to be conducted in extended low gravity available on spacecraft in low-Earth orbit. Limited near-term flight opportunities for investigations capable of making use of existing hardware, where little or no minor modifications would be required, are anticipated in the future. In addition, preparations are underway for possible flight experiments using the International Space Station (ISS) through development of modular research instruments that will accommodate multiple experiments and multiple users. **However, it should be noted that the Physical Sciences Research Division does *not* plan to make selections for flight definition investigations in Fluid Physics in this current NRA.** Fluid physics investigations fall into the following sub-discipline areas: Complex Fluids, Interfacial Phenomena, Multiphase Flow and Heat Transfer, Biofluids, Dynamics and Instabilities, and Exploration.

RESEARCH ANNOUNCEMENT OBJECTIVES

This NRA focuses and enhances the fluid physics program through the solicitation of

1) Experiment concepts defining and utilizing new instruments for future space-based experiments in fluid physics with emphasis on research concepts that can be accommodated by compact and innovative instrumentation.
2) Ground-based experimental and theoretical studies leading to potential new flight investigations or enhancing the understanding of existing experiments in fluid physics with emphasis on research that will provide a scientific foundation for technologies required by future human and robotic space missions.
3) Interdisciplinary research projects utilizing teams of researchers from multiple disciplines (e.g., optics, materials science, combustion, bioengineering, etc.) to advance technology, promote ground-breaking research, and support technology transfer. A single researcher who is able to identify past work that has an interdisciplinary thrust may also propose with a well defined proposal citing all of his/her previous work which incorporates the interdisciplinary approach. Interdisciplinary proposals should clearly identify key personnel and their fields of expertise. It must be clearly stated who the Principal Investigator and the lead institution are and how the effort will be integrated. Such proposals should state how teaming and cooperation between the engineering and science teams would be managed. Management structure, goals, and cooperation with the research community to facilitate the transfer of technology must be evident in the proposal.

In support of the goal of human space exploration through science and technology, individuals participating in the research program are encouraged to help foster the development of a scientifically informed and aware public. The research program represents an opportunity for NASA to enhance and broaden the public's understanding and appreciation of the value of research in the environment of space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and fluid physics through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating the value and importance of their work to the public.

II. PROGRAM RATIONALE

Fluid Physics has a crucial role in supporting enabling technologies for long duration human space flight. Research is needed to support several technologies such as: power generation and storage, space propulsion, life support, and materials production and storage.

The fluid physics program encompasses a wide range of research in physics and engineering science, including studies of heat and mass transfer processes, fluid dynamics, and the physics of complex fluids. In this NRA, emphasis is being placed on enhancing understanding of fluid physics phenomena in support of space flight and the safety and health of astronauts "living in Space."

Fluid physics is the study of the properties and motions of liquids and gases. Such studies arise from nature (e.g. in meteorology, oceanography, and living plants or animals) and technology (e.g. in biological, chemical and material processing, and fluid systems). Fluid phenomena span scales that range from nanometers to light years and constitute by their ubiquity one of the fundamental areas of science and engineering. The need for better understanding of fluid phenomena has created a vigorous, multi-disciplinary research community in fluid physics, whose continuing growth has been marked by the steady emergence of new fields of relevance in both basic and applied science. Areas of technological and ecological importance such as global atmospheric change, groundwater pollution, oil production, and advanced materials manufacturing often rely for their progress on advances in fluid physics. Scientists studying basic problems from chaotic systems to the dynamics of stars also turn to fluid physics for their models. Through the history of fluid physics, theory and experiment have maintained a synergetic relationship in building scientific knowledge. In recent years, research in fluid physics has been at the forefront in applying large-scale computational techniques to physical problems. The continuing advance of high-performance computing will drive new theoretical insights, which will spur a new generation of experimental fluid physics.

Gravity strongly affects many phenomena of fluid physics that drive motions, shape boundaries and compress fluids. Further, the presence of gravitational forces can mask effects of other forces that are ever present but comparatively small.

Microgravity research encompasses the phenomena related to gravitational fields (or equivalent accelerations with respect to inertial frames) whose magnitudes are but a small fraction of Earth's gravity. Fluid physics has a unique role in the NASA microgravity science program. Gravitational physics deals directly with the existence of gravity. Other scientific disciplines are interested in developing the potential of the microgravity environment as a research tool and hope to create controlled conditions of fluid flow and heat and mass transport in specialized circumstances, e.g. the growth of protein crystals, the solidification of a molten semiconductor, or the burning of liquid fuels. The goal of much of fluid physics research is simply to comprehend fundamental physical phenomena. In doing this, fluid physics contributes to seemingly distant fields of research by providing a fundamental framework of principles and basic understanding for flow and transport that specialists in other disciplines can apply to their problems.

III. CURRENT PROGRAM CONTENT

We are currently funding approximately 15 flight and 100 ground–based investigations encompassing both experimental and modeling activities. These may be divided into a number of categories as follows:

- COMPLEX FLUIDS

Complex fluids comprise a large class of soft materials, which often consist of mesoscale supramolecular aggregates, ranging in size from ~1 nm to ~1 micron. Their physical properties are determined by the interplay of entropic and structural intermolecular forces and interfacial interactions. Examples are microemulsions, foams and suspensions of colloids or microgels, liquid crystals, biological membranes, the intracellular macromolecular scaffolds of cytoskeleton and the extracellular matrix. The highly interdisciplinary field of complex fluids thus bridges the gap between synthetic and living materials. Aside from the scientific challenges, Complex Fluids have a broad range of industrial, biological and environmental applications. Examples are soaps, polymeric lubricants and emulsifiers, and drug delivery systems. Brownian motion keeps these mesoscopic particles in suspension even in the presence of gravity, but the relatively small sedimentation, which normally occurs, can have profound effects on ordering, crystallization, and equilibrium structures. Near absence of gravitational force in space, therefore, provides an ideal laboratory for studying long-term equilibrium properties of complex fluids. In case of hard sphere colloids, this has been demonstrated by experiments conducted in space under NASA's microgravity research program. Experiments conducted in space show formation of dendritic crystals and crystallization of colloidal samples that stay in the glass phase for years on Earth. Some specific examples of complex fluids research areas are provided below.

1. <u>Colloids and Suspensions</u>: Colloids are used to study phase transitions and fluid behavior and can be used to model atomic systems.
2. <u>Nanoscale Fabrication in the Fluid Phase</u>: Self-assembly of colloids offers a direct route to fabrication of nanoscale devices with controllable structure and properties.
3. <u>Granular Mechanics</u>: Granular media represent an interesting class of materials that can exhibit a spectrum of complex flow behavior, ranging from solid-like to gas-like.
4. <u>Non-Newtonian Fluids</u>: Complex fluids such as polymers, liquid crystals, slurries and suspensions exhibit nonlinear material response to imposed deformations.
5. <u>Near-Critical Point Fluid Behavior</u>: A pure fluid near its liquid-vapor critical point exhibits universal and interesting properties. For example, a simple fluid such as Xenon is known to exhibit non-Newtonian visco-elastic behavior near its critical point.

- INTERFACIAL PHENOMENA

Understanding behavior of fluids at a solid-liquid-gas tri-junction as well as liquid-gas/vapor interfaces is not only a subject of scientific curiosity but also of great technological interest. Many natural and technological processes and phenomena, such as coating and painting of surfaces, morphological stability of interface during crystallization, oil recovery from shale, and liquid mediated chemical reactors, rely on the fluid mechanics of the solid-liquid-gas tri-junction. Gravity, on Earth, tends to overwhelm the effects of surface tension force except in a very thin layer of fluid in the vicinity of the solid-fluid interface. In microgravity, the region influenced by surface tension is magnified considerably, allowing one to probe the characteristics of this region with much greater precision and insight. Also, the behavior of liquid-vapor/gas interface in microgravity is a subject of great interest for engineers dealing with liquid management in partially filled tanks in space. Examples include:

1. <u>Capillary Phenomena:</u> Earth gravity overwhelms the effects of capillary forces except for a thin layer near the solid-fluid interface. In microgravity, surface tension can control the shapes of liquid bodies of even large scale, leading to configuration changes that can be important in the drainage of fuel tanks and generally in the area of fluid handling.
2. <u>Solid-Liquid Interactions:</u> Contact-line dynamics of fluid-fluid-solid tri-junctions can control coating of solid surfaces, cooling of hot surfaces, and behavior of vapor bubbles in nucleate boiling.
3. <u>Coalescence and Aggregation Phenomena:</u> Numerous phase-separation processes rely on coalescence or aggregation of dispersed phases to form continuous phases. Boiling, condensation, foam drainage and coarsening formation, and (Ostwald) "ripening" of solid

precipitates are familiar examples.
4. Drops and Bubbles: The microgravity environment allows the use of sample levitation methods to study the capillary dominated phenomena affecting the dynamic and static behavior liquid drops in air and gas/vapor bubbles in liquid.

- MULTIPHASE FLOW AND HEAT TRANSFER

Due to relatively large density differences between phases, gravity tends to exert a controlling influence on multiphase flows and phase changes. Microgravity behavior of such systems often differs markedly from normal-gravity behavior. Many advanced concepts for power generation, energy storage, thermal management, and life support in space rely on multiphase flow and phase change; accordingly, understanding of multiphase flow and phase change in microgravity is of critical importance for NASA's space exploration needs.

1. Flow Regimes and Regime Transitions: Multiphase flows normally configure themselves into distinctive flow regimes in which the various phases are non-uniformly distributed across the duct through which they flow.
2. Pool and Flow Boiling: Nucleate boiling is one of the most efficient heat transfer mechanisms, not only on Earth, but also for space applications where the size and mass of the equipment are critically constrained.
3. Condensation: Devices such as capillary pumped loops, loop heat pipes, and two-phase radiators depend critically on condensation.
4. Gas-Liquid Flow through Packed Beds: Gas-liquid two-phase flow through a fixed bed of particles occurs in many unit operations of interest to the designers of space-based and terrestrial equipment.

- BIOFLUIDS

Biofluids, an intersection of fluid physics and biology, is a new area of emphasis within the Office of Biological and Physical Research. Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. An adequate understanding of the underlying fluid physics and transport phenomena can provide new insight and techniques for analyzing and designing systems that are critical to NASA's mission. Applications derived from biology and physiology can enrich the fluid mechanics and transport phenomena research performed by investigators of the microgravity fluid physics community.

1. Physiological Systems: The microgravity environment modifies vascular fluid distribution on a short time scale, due to the loss of hydrostatic pressure, and on a longer time scale, due to the shift of intercellular flows. This fluid shift could modify transport processes throughout the body.
2. Cellular Systems: It has been shown that removal of gravity can impact cell differentiation, thus providing an important tool in the search for microenvironmental cues (bioactive molecules, local forces including adhesion), which contribute to organ assembly and tissue-specific differentiation.
3. Biocrystals and Biomaterials: Fluid physics and transport phenomena play a key role in determining the morphology of biocrystals. In normal gravity, buoyancy driven convection can alter the concentration fields and resulting properties of crystalline structures. The microgravity environment allows diffusion-controlled processes to govern such phenomena under certain circumstances.
4. Biochip Research: The heart of biochip devices is a miniaturized microfluidics system capable of moving liquids containing various reagents and samples to and from holding regions. Integrating on-board valves, mixing, and other standard fluid handling devices together with on-board detection systems have enabled rather complex, analysis-specific systems to be developed.

- DYNAMICS AND INSTABILITIES

Buoyancy is one mechanism by which Earth's gravity can exercise a strong influence on flow. Many well-known flow instabilities, such as Rayleigh-Bénard instability, are controlled by gravity. When gravitational force is removed, other forces such as surface tension can exercise significant influence on many flows. The Marangoni-Bénard instability is an example of surface tension controlled phenomena. This subdiscipline of fluid physics deals with a broad category of flow phenomena where the absence of gravity can produce new flow physics.

1. Thermocapillary and Solutocapillary Phenomena. When a fluid-fluid interface is subjected to a tangential gradient of temperature and/or species concentration, shear stresses are created in the interface, which drive bulk motions. Such surface effects can control the migration of droplets in bulk or along solid surfaces.
2. Electrokinetics and Electrochemistry. Electrokinetics concerns transport phenomena involving charged fluid interfaces and their associated diffuse layer of space charge.
3. Geophysical Flows: Accurate prediction of weather is an everyday concern, with enormous ramifications for most human activity. It is the coupled ocean-atmosphere fluid system that controls the weather and its long-term trend, the climate. The fluid mechanics of this system falls in the realm of geophysical fluid flows.

- EXPLORATION RESEARCH AND TECHNOLOGY

As one of NASA's five core Strategic Enterprises, the Office of Biological and Physical Research (OBPR) Enterprise will provide the research efforts required to obtain fundamental understanding and achieve science breakthroughs to enable safer, more efficient, more productive, and more affordable Human Exploration of Space. The Space Studies Board of the National Research Council has concluded in a recent report ("Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies," Space Studies Board, National Research Council, 2000) that extraordinary improvements need to be made in several areas for NASA to achieve exploration goals. These areas include power generation/storage, space propulsion, life support, hazard control, material production/storage, and fabrication and maintenance. Fluid Physics plays a significant role in many systems and subsystems related to these areas. The need for improved understanding of both gravity- and non-gravity-based fluid phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. Specific exploration areas of interest include

1. Gravity-Dependent Phenomena: Examples include: (a) Microfluidic flow–biochip design, fuel cells, etc; (b) Multidimensional two-fluid models; (c) Two-phase flow through packed beds; (d) Detailed stability studies on boiling/condensation; (e) Surface-tension-related phenomenon – wetting; (f) Marangoni convection; (g) Sloshing problems; (h) Cryogenic and thermal control systems; and (i) Granular flow and dust.

2. Non-gravity-Dependent Phenomena: Nanotechnology & Biomolecular Applications: Recent breakthroughs in using biomolecular based nanoscale motors and switches have opened up the possibility of a new class of devices/sensors for space as well as terrestrial applications. Such devices offer the promise of extreme compactness with potential for self-healing and adapting to the changing environmental conditions. Many processes used to achieve biomolecular self-assembly are likely to take place in a fluid phase. Therefore, an understanding of associated fluid mechanics, heat and mass transport may be crucial to the development of practical biomolecular/nanoscale technologies. NASA would like to encourage groundbreaking cross-disciplinary research in this evolving field. Proposals in this area need not provide a strong justification for microgravity relevance.

IV. FUTURE DIRECTIONS OF THE PROGRAM

The Microgravity Fluid Physics Program may shift its focus by reorganizing its research into three categories: Fundamental Research in Microgravity, Exploration Research and Technology, and BioScience and Engineering Research.

FUNDAMENTAL RESEARCH

Investigations that need the microgravity environment to expand the current knowledge of understanding. Examples include:

Morphology and Rheology of Colloids
Surface Tension on Fluid-Fluid Interfaces and Fluid-Fluid-Solid Trijunctions
Transport Phenomena Involving Charged Fluid Interfaces
Capillary Phenomena Affecting Drops and Bubbles
Non-Newtonian Behavior of Complex Fluids

EXPLORATION RESEARCH AND TECHNOLOGY

Research and technology enabling long duration human space flight. Such missions may include Mars exploration or even deep space exploration that would require, for example, advanced power, propulsion, life support systems and material production. Examples include:

Pool and Flow Boiling
Gas-Liquid Flow through Packed Beds
Miniaturized Chemical and Physical Process Equipment (applicability for space in-situ resource utilization applications)
Granular Flows
Dust Flow and Particulate Control

BIOSCIENCE AND ENGINEERING RESEARCH

Fluid mechanics and transport processes play a critical role in many biological and physiological systems and processes. Examples of this interdisciplinary research include the following.

Microfluidics and Lab-on-the-Chip Technology
Nanoscale Fabrication and Self Assembly Processes (often take place in the fluid phase)
Flow and Transport in Bioreactors, Cell Cultures, and Protein Crystallization
Fluid Physics aspects of Biomedical Processes in Space

Fluid physics and transport in biological systems is becoming of increasing interest in the understanding of some debilitating aspects of prolonged microgravity exposure, such as bone loss, orthostatic intolerance, and cephalad fluid shift, and fluid physics research can also aid in the effective development of countermeasures that will be necessary for long-term human presence in space.

V. HARDWARE AND FACILITY DESCRIPTIONS

The Physical Sciences Division (PSD) is pursuing a program for the development of International Space Station payloads that can be configured (or reconfigured) to accommodate multiple users. This evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the eventual development of experiment payload technologies for research throughout the era of the ISS.

1. <u>CURRENT AND PLANNED FLIGHT HARDWARE</u>

A. ISS FLUIDS INTEGRATED RACK (FIR): The International Space Station United States Laboratory Module will support the Fluids and Combustion Facility (FCF) currently under development at the Glenn Research Center. The FCF is a modular, multi-user, microgravity science facility. Together the racks will provide the fundamental physical and functional infrastructure necessary to perform combustion science, fluid physics, and adjunct science experiments on-board the ISS. Please see the following Web site: http://fcf.grc.nasa.gov/pages/hometxt.html

B. FIR EXPERIMENT-SPECIFIC HARDWARE: The FIR features the capability to remove and replace different PI-specific experiment packages. A number of investigation-specific hardware packages are currently under development or are planned for development and are listed below as typical examples of FIR experiment specific hardware.

a. Light Microscopy Module (LMM)
b. Bubbly Suspension Research Apparatus
c. Granular Flow Module (GFM)
d. Contact Line Dynamics Apparatus
e. Foam Experimentation Apparatus
f. Pool Boiling Module (PBM)

C. NASDA FLUID PHYSICS EXPERIMENT FACILITY (FPEF): This Fluid Physics Experiment Facility (FPEF) is undergoing development by the National Space Development Agency of Japan (NASDA) for the Japanese Experiment Module (JEM) of the International Space Station. It is a multi-user facility designed to perform fluid physics experiments at an ambient temperature and consists of a main body and an experiment section. The experiment cell is 350 mm (W) x 350 (D) x 300 (H). The maximum electric power available is 978 watts. Several diagnostic techniques will be included. Additional information can be found at http://jem.tksc.nasda.go.jp/kibo/kibomefc/fpef_g_e.html

D. ESA FLUID SCIENCE LABORATORY (FSL): The European Space Agency (ESA) is developing the Fluid Science Lab (FSL) to be operated in the Columbus Orbital Facility (COF) of the International Space Station. FSL provides the interfaces for a thermally controlled environment to perform experiments in the field of fluid physics, i.e. experiments with optically transparent media and is equipped with a large standard set of advanced optical diagnostics, especially different types of interferometers. FSL is an upgrade of a previous ESA developed fluids facility—the Bubble Drop Particle Unit. As with BDPU, the FSL supports scientific microgravity research in many areas of fluid physics. Phenomena can either be observed inside transparent media or on opaque surfaces. Examples of types of investigations supported are hydrodynamic behaviors of fluid systems, phase interface behaviors of non-equilibrium fluid systems; surface deformations and oscillations of fluid bridges, nucleation and condensation phenomena in over-saturated and sub-cooled liquids, and critical point phenomena. Examples of new areas are Aerosol/Colloid Research, Plasma Crystals and Solution/Gel Crystal Growth. Additional information can be found at http://www.estec.esa.int/spaceflight/map/fsl/fsl.htm

E. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC): DECLIC is a new, modular, multi-user facility currently being designed and built by the French Space Agency, CNES, for use aboard the International Space Station. This facility is being designed to conduct microgravity investigations in critical phenomena and directional solidification of transparent alloys. Specifically, DECLIC will accommodate chemical-physical studies of supercritical pure fluids with a critical temperature lower than 100°C and a critical pressure lower than 100 bar such as CO_2, SF_6, and Xe, and supercritical pure fluids and solutions with a critical temperature lower than 600°C and a critical pressure lower than 500 bar such as H_2O and aqueous solutions. It will also accommodate microgravity investigations in morphological stability at the solid/liquid interface during crystal growth in transparent alloys. In addition, investigations in condensed matter physics requiring a long term microgravity environment can also take advantage of the capabilities offered by DECLIC. More detailed information about DECLIC can be obtained at the CNES Web site:
http://www.estec.esa.nl/spaceflight/map/fsl/declic.htm

F. PHYSICS OF COLLOIDS IN SPACE APPARATUS (PCSA): Information can be found at http://microgravity.grc.nasa.gov/6712/pcs.htm

G. EXTENSIONAL RHEOLOGY INSTRUMENT: Information can be found at http://microgravity.grc.nasa.gov/EXPR/NONNEW.HTM

H. MECHANICS OF GRANULAR MEDIA APPARATUS (MGMA): Information can be found at http://science.nasa.gov/headlines/y2000/ast17nov_1.htm

I. ISS MICROGRAVITY SCIENCE GLOVEBOX: Information on the MSG can be found at, http://flightprojects.msfc.nasa.gov/fd36_msg.html, or http://payloads.msfc.nasa.gov/MSG/

J. GLOVEBOX EXPERIMENT HARDWARE
   1. Glovebox Laser Light Scatterer
   2. SHERE

2. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced gravity research facilities that support the microgravity fluid physics program include two drop towers at the Glenn Research Center (GRC), and parabolic flight research aircraft at the Johnson Space Center (JSC). A variety of specialized test rigs have been constructed and used to conduct a wide range of microgravity fluid physics research. These rigs have been developed to accommodate specific individual investigator's requirements. In addition, other capabilities have been developed which have the potential for use by multiple investigators and investigations. These facilities and rigs are listed below.

A. 2.2-SECOND DROP TOWER
B. 5.18-SECOND ZERO-GRAVITY FACILITY
C. PARABOLIC FLIGHT RESEARCH AIRCRAFT (LOW GRAVITY)
D. TWO-PHASE FLOW TEST RIG
E. COMPUTATIONAL LABORATORY
F. MOTION ANALYSIS AND OBJECT TRACKING SYSTEM: (TRACKER)
G. COMPLEX FLUIDS CELL FLIGHT HARDWARE LAB

3. FLUID PHYSICS DIAGNOSTIC and MEASUREMENT CAPABILITY

NASA has adapted or developed a number of diagnostic and measurement techniques for microgravity fluid physics research that can be utilized for ground-based research and possibly modified for flight research. Techniques under development that are expected to become available in the near future or are currently available are listed below.

A. Laser Tweezers Facility
B. Surface Light Scattering Hardware
C. Common-Path Interferometry (CPI)
D. Stereo Imaging Velocimetry (SIV)
E. Forward Scattering Particle Image Velocimetry
F. Birefringence Measurements
G. Laser Feedback Interferometry
H. Diffusing Wave Spectroscopy (DWS)
I. Two dimensional particle imaging velocimetry
J. Rainbow Schlieren for measurement of temperature distributions
K. Light sheet flow visualization and/or velocimetry
L. Miniaturized laser Doppler velocimetry
M. Liquid surface temperature and vapor phase concentration measurements via exciplex fluorescence

VI. NRA FUNDING AND SCHEDULE

The total funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon availability of appropriated funds from which payment for awards can be made and upon the receipt of proposals which the Government determines are acceptable for an award under this NRA.

The Physical Sciences Research Division does *not* plan to make selections for flight definition investigations in Fluid Physics in this current NRA. However, approximately 30 ground-based study proposals from those judged to be highly meritorious will be funded at an average of $110,000 per year, for up to 4 years. Also, if the proposal is of high value and receives an excellent review, NASA may consider higher funding levels for such proposals. The initial fiscal year (FY) 2004 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year.** Specifically, the resources required for the first year should not be overestimated. The proposed budget for ground-based studies should include salaries, equipment, supplies, travel to science and NASA meetings, other expenses such as publication or computing costs, and indirect costs.

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 p.m. EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

Notice of Intent Due: October 15, 2002

Proposal Due: December 2, 2002

Final Selections: June 2003

Funding Commences: No sooner than November 2003
(dependent upon actual selection and procurement process)

VII. BIBLIOGRAPHY

Documents and Web sites that may provide useful information to investigators are listed below.

1) Microgravity Research Facilities and Fluid Physics Flight Experiments, Microgravity Science Division, NASA Glenn Research Center, http://microgravity.grc.nasa.gov/
2) Fluid Physics Program, http://microgravity.grc.nasa.gov/6712/fptp.html
3) Fluids and Combustion Facility, http://fcf.grc.nasa.gov/
4) Office of Biological and Physical Research (OBPR) at NASA Headquarters, http://spaceresearch.nasa.gov/
5) Microgravity Research Program Office at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov
6) STS Investigators' Guide, NASA Marshall Space Flight Center.
7) Second Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3267, June 1994.
8) Third Microgravity Fluid Physics Conference Proceedings, NASA Conference Proceedings 3338, June 1996.
9) Fourth Microgravity Fluid Physics Conference Proceedings, National Center for Microgravity Research on Fluids and Combustion, August 1998, http://www.ncmr.org/events/fluids1998.html
10) Fifth Microgravity Fluid Physics Conference Proceedings, National Center for Microgravity Research on Fluids and Combustion, August 2000, http://www.ncmr.org/events/fluids2000/index.html
11) Microgravity Science and Applications Program Tasks and Bibliography, 2000, http://peer1.nasaprs.com/peer_review/taskbook/micro/mg00/mtb.cfm
12) Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA Conference Publication CP-1998-207431ftp://ftp-letrs.lerc.nasa.gov/LeTRS/reports/1998/CP-1998-207431.pdf
13) NASA Reduced-Gravity Carrier Options for Microgravity Experiment Operations, http://peer1.nasaprs.com/peer_review/prog/CarrierOptions.pdf

Questions about this program element may be directed to the Microgravity Fluid Physics Enterprise Scientist:

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Background materials are available upon request from

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APPENDIX E
NRA 01-OBPR-08

MICROGRAVITY FUNDAMENTAL PHYSICS: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

NASA has supported research in Fundamental Physics for over two decades. Initially, the program focused on studies of critical phenomena in the Low Temperature and Condensed Matter Physics (LTCMP) area. Over the last decade, the program has been extended to also include research in the fields of Laser Cooling and Atomic Physics (LCAP), Gravitational and Relativistic Physics (GRP), and Biological Physics (BP).

The over-arching program goal is to unlock mysteries of the Universe by exploring the frontiers of physics using laboratories in space. Ground-based research is used to gain a preliminary understanding of phenomena and to define experiments to be conducted during extended exposure to the space environment using spacecraft in low-Earth orbit. These studies form the foundation for our research program and serve as the intellectual underpinning of the investigations to be conducted in space.

The primary focus for future research activities in this area will be on flight opportunities using International Space Station research instruments. NASA is currently studying the development of modular research instruments that can be configured (or reconfigured) to accommodate multiple experiments and multiple users. This is envisioned as an evolutionary program with the objectives of providing experimental data in response to increasingly sophisticated science requirements and of permitting the evolution of experimental approaches and techniques as needed for scientific investigations throughout the era of the International Space Station. This announcement is being released as part of a coordinated series of discipline-directed solicitations intended to span the range of NASA's Physical Sciences Division's program.

While research into fundamental physical properties of nature is still considered to be the most important component of our research program, there is also an opportunity with this solicitation for interdisciplinary research and for development of advanced technologies that can benefit future science activities. Examples of technologies of interest to NASA are those based on coherent quantum phenomena. Sensors and detectors based on such phenomena may enable entirely new research activities.

II. PROGRAM RATIONALE

This NRA is intended for research activities in fundamental physics that can utilize the unique environment of space in an important way.

Problems in physics where the space environment can be beneficial include those sub-fields

- where interactions are weak;
- where extremely uniform samples free from hydrostatic compression are required;
- where objects must be freely suspended and their acceleration must be minimized;
- where space offers a unique environment not available on Earth;
- where the mechanical disturbances, unavoidably present in an Earth-bound laboratory, must be eliminated.

One category of experiments can benefit either from the free fall environment available in space, or from the use of variable gravity as a parameter whose change may lead to the elucidation of otherwise hidden properties and phenomena. The physics of critical points in fluids is prominent among the issues in condensed matter physics that have been investigated so far under free-fall conditions. Microgravity plays an important role in these investigations because the closeness of approach to a critical point in the Earth-bound laboratory is limited not by the skills of the experimentalist, but rather by the uniformity of the sample that is spoiled by hydrostatic pressure variations.

A second category of phenomena currently under investigation requires atoms to be retained virtually without motion and distortion in a cavity for extended time intervals. However, the length of time that the atoms can be held in the cavity is limited by the gravitational acceleration experienced on Earth. Studies of laser-cooled atoms exemplify experiments in this category.

A third category of studies includes those that can benefit from the opportunity to virtually eliminate all mechanical disturbances in space. For example, such disturbances limit experiments based on proof-mass techniques to probe fundamental questions in gravitational and relativistic physics, where the positions of objects relative to each other must be maintained and measured with a resolution unobtainable in the gravitationally noisy environment on Earth.

A fourth category of investigations benefit not from the free-fall of orbital flight, but rather from other aspects of the space environment, such as the availability of new space-time coordinates, different gravitational potentials, or environmental effects peculiar to space.

One of the unifying characteristics of physics as a whole is that the field addresses fundamental issues that transcend the boundaries of a particular field of science.

It is typical that, at one extreme, the fundamental laws of our universe, such as the law of gravitation or the laws that rule the quantum world, should be a central issue. Clearly these laws are relevant to various extents in many branches of science. At another extreme, in condensed matter physics and biological physics, those unifying principles are studied which arise from the interaction of many degrees of freedom on vastly different length scales. Examples of this type of study can be found in the research on critical phenomena mentioned above, which addresses fundamental problems of nonlinear physics that pertain equally to fluid, solid-state, chemical, or biological systems.

Space experiments offer an opportunity to extend a set of measurements beyond what can be done on Earth, often by several orders of magnitude.

This extension can lead either to a more precise confirmation of our previous understanding of a problem, or it can yield fundamentally new insight or discovery. NASA maintains a vigorous program of Earth-bound investigations, together with an appropriate number of space-based projects. The motivation for this dual approach to maximizing scientific output is two-fold. Firstly, in most cases, only a vigorous ground-based program will identify the experiments that are most worthy of consideration for space. Thus, it is expected that the space experiments are a natural outgrowth of the ground-based program. Secondly, a space experiment should have been performed on Earth to its maximum potential. This should determine whether a highly complex experiment would be successful when conducted in space. It also ensures that the value of the science knowledge to be gained by a space experiment cannot be greatly diminished by Earth-bound experiments.

With this solicitation, NASA intends to select both flight-definition and ground based research proposals. Approximately 6 to 7 innovative flight-definition investigations for the ISS in the 2006 timeframe are targeted for support. Approximately 30 to 40 ground-based investigations covering experimental studies with the potential for future flight, theoretical studies to support current or planned flight experiments, and investigations aimed at developing research-enabling technology will be supported. Actual numbers of selections will be influenced by the response from the scientific community.

III. CURRENT PROGRAM CONTENT

NASA is currently funding approximately 70 investigations in fundamental physics. About 4 in every 5 investigations are ground studies, with the remainder being either flight or flight definition studies. Both experimental and theoretical activities are being supported. The main sub-disciplines and study areas currently supported in the program are described below.

Low Temperature and Condensed Matter Physics: Critical phenomena, boundary and finite size effects, non-equilibrium systems, solid to liquid transitions, superfluid hydrodynamics, and thick fluid films.

Laser Cooling and Atomic Physics: Fundamental forces and symmetries, Bose-Einstein condensation and quantum gasses, atomic interferometers, atom optics, and atomic clocks.

Gravitational and Relativistic Physics: Einstein's relativity theories and other gravitation theories, Einstein's equivalence principle.

Biological Physics: Non-linear dynamics of biological specimens, manipulation of biological specimens, and self-assembly.

Technology: Sub-kelvin refrigeration technology, single bio-molecule dynamics, and diagnostics development.

More detailed information about the current program can be found in the Bibliography section.

IV. FUTURE DIRECTIONS OF THE PROGRAM

The Fundamental Physics Discipline Working Group has carefully considered and advised NASA on future research directions for this discipline. NASA has considered these recommendations in establishing the future program directions description shown below. In addition, NASA will consider proposals in research areas not described in this announcement, where the space environment offers a significant advantage to researchers in helping us understand and describe the Universe and the physical laws governing its behavior.

With this solicitation, NASA is interested in selecting innovative flight-definition investigations that can take advantage of future opportunities aboard the International Space Station; ground-based experimental investigations with a potential for future flight; theoretical investigations supporting current or future flight experiments; and investigations aimed at developing research-enabling technology. The description of the research hardware under development can be found in Section V.

- LOW TEMPERATURE AND CONDENSED MATTER PHYSICS (LTCMP)

1. **Critical Phenomena**. The physics of critical-point systems is extremely diverse, but at the same time, it is unified through the framework of the RG theory. Two important critical points that have proven to be excellent test systems for the RG theory are the superfluid transition in liquid helium and the liquid-gas critical point. A third important test system is the tricritical point in ^{3}He-^{4}He mixtures. As well, room temperature critical point experiments concerning the turbidity of fluids near liquid-gas critical points can provide new information about the interactions of the density fluctuations.

2. **Solid-Fluid Interfaces**. One important issue in condensed matter physics concerns the nature of the interface between solids and fluids. The boundary conditions that prevail at this

interface have an influence on macroscopic phenomena, but the microscopic aspects of the system near the boundary are difficult to study. Because the fluid near a critical point has a boundary layer of macroscopic thickness, a critical fluid system that is confined can be used to improve the study of boundary effects. Issues include the influence of the boundaries on thermodynamic properties and the influence on transport properties such as heat or mass transport.

3. **The Physics of Thick Fluid Films**. The study of fluid films under typical terrestrial conditions is limited to films with a thickness of no more than tens of nanometers, because thicker films will “drain." Interesting new physics could be learned from the study of thicker films that would be available in a free-fall environment.

4. **Non-equilibrium Systems**. Nature displays many non-equilibrium systems that are constantly evolving. Yet most studies of physics consider the idealized case of equilibrium. The statistical dynamics of many-particle systems in metastable equilibrium or in non-equilibrium is an important field of physics that is far from being well developed and well understood. The criticality of a system can be exploited to explore extreme non-equilibrium conditions where transport becomes a nonlinear phenomenon.

5. **Superfluid Hydrodynamics**. A number of highly interesting experiments in superfluid hydrodynamics exist that can be carried out under free-fall conditions. One class addresses the intrinsic nucleation problem for quantized vortices in helium II. In yet another experiment, a helium drop could be rotated rapidly to observe the deformation from the spherical shape against the force of surface tension. Creation and suspension of drops offers other classes of experiments studying collisions of drops and coalescence. At low enough temperatures, hydrogen also behaves as a quantum fluid (or solid), and perhaps even as a superfluid, providing new scientific insight.

6. **Melting-Freezing and the Growth of Quantum Crystals**. First-order phase transitions involving melting and freezing processes have long been of fundamental interest to physicists and of practical importance to material scientists. Prominent among the fundamental issues of interest are the mechanisms involved in the transfer of atoms from liquid to solid and vice-versa, nucleation (initiation) of a new phase within an existing one, and diffusive and ballistic mass transport. In addition, an important aspect of crystal formation involves the phenomena that govern the evolution of crystal shapes, that is, the so-called roughening transition and associated phenomena. Many of these fundamental issues can be studied exceptionally well at low temperatures, where the solidification of quantum crystals offers systems devoid of impurities and essentially free from non-equilibrium defect concentrations. In the presence of gravity, various forms of convective flow and deformation of the equilibrium liquid-solid interface by gravity have inhibited detailed studies of many of these processes.

- LASER COOLING AND ATOMIC PHYSICS

1. **Fundamental Forces and Symmetries.** Almost every precise measurement made in science ultimately traces back to a time or frequency measurement. NASA is currently developing space clocks with one to two orders of magnitude better precision than existing ground clocks by taking advantage of the free-fall environment available on the ISS. At the heart of the atomic clock is a measurement of a carefully chosen energy level splitting within the atom. These splittings are nature's own reference “standards" and are sensitive to subtle aspects of fundamental forces and to basic symmetries of nature. Ultra-high precision atomic measurements can make important contributions to answering questions ranging from predictions of string theory and M-theory, searching for the possible variation of fundamental constants, and examining the robustness of the fundamental symmetries that underlie the basis of the Standard Model. Use of space can play a vital role in exploring these and related problems.

2. **Bose-Einstein Condensation (BEC) and Quantum Gases**. The physics of laser-cooled vapors is closely tied to the physics of quantum fluids. Recently, dramatic advances in the condensation of large numbers of atoms into the BEC state and new insight into quantum transport phenomena has been gained. As lower and lower temperatures are achieved using evaporative cooling, gravitational limitations are emerging. For example, the energy bias introduced by the gravitational field reduces the efficiency of evaporative cooling, the final cooling step used to pass into the BEC phase. Investigating freely expanding sub-nanokelvin condensates and very dilute condensates at higher precision will become increasingly difficult on Earth's surface due to gravitational effects. BECs can be used to study quantum vortices and to study problems related to astrophysics in the laboratory.

3. **Atom Optics**. The atom interferometer is one example of the remarkable devices being developed in the field of atom optics, which explores the analogy between de Broglie matter waves and ordinary electromagnetic light waves. Atomic lasers in which matter waves are coherently coupled out of Bose-Einstein condensates have been demonstrated, along with atomic mirrors, beam splitters, and nonlinear 4-wave mixing devices. In many of these experiments, Earth's gravity field limits what can be achieved in ground laboratories so that significant advances may be achieved in orbit.

4. **Atomic Interferometers**. Interferometers represent a particularly important aspect of atom optics. Reaching far beyond the initial goal of demonstrating the interference of matter waves of massive, complex particles, the atom interferometer is now used to realize high performance rotation sensors (gyroscopes) and gravitometers that provide unprecedented sensitivity. The elimination of disturbing gravity effects allows significant improvements for many interferometer experiments. These techniques can also be applied to the study of fundamental problems, such as improving our knowledge of the gravitational constant G, and searching for possible violations of Einstein's general relativity and other metric theories of gravity.

- GRAVITATIONAL AND RELATIVISTIC PHYSICS

1. Tests of Theories of Gravitation. Tests of Einstein's theories of relativity and of other metric and non-metric theories of gravitation serve as a foundation for understanding how matter and space-time itself behave at large length scales and under extreme conditions. The free-fall environment of space, the use of low-temperature techniques, the application of laser cooling and mass interferometer techniques, and the use of high-precision frequency standards all offer opportunities to perform improved tests of these theories significantly beyond what is possible on the ground.

2. Test of Einstein's Equivalence Principle (EEP). The EEP provides a foundation for all metric theories of gravity and is crucial to the quest for unifying all fundamental forces of nature. Despite the beauty and profundity of Einstein's theory and the success of the Standard Model, our present understanding of the fundamental laws of physics has shortcomings. At present, no realistic theory of quantum gravity exists. The Standard Model suffers from unresolved problems concerning the violation of the Charge-Parity symmetry between matter and antimatter and the various unexplained mass scales. Suggested solutions to these shortcomings typically involve new interactions that could manifest themselves as apparent violations of the EEP. The construction of a "Grand Unified Theory" of weak, electromagnetic and strong interactions may include the existence of a super symmetry between half integer fermion and integer boson particles. This framework suggests the existence of new interactions beyond those of the Standard Model. For example, the exchange of spin-one particles could lead to a new repulsive force between macroscopic bodies, which might be detected through small EEP deviations; or a (near) massless scalar field could either modify metric gravity or produce violations of EEP. One of the most important predictions based on super symmetry is the existence of the axion, which mediates a force between mass and intrinsic spin. Confirmation of this prediction would have a major impact on our understanding of the universe. In a space environment, the weak equivalence, local Lorentz invariance, and local position invariance aspects of EEP can be tested independently at high precision to search for indications of such new features of physical law. Measurements of the gravitational red shift also test important aspects of the local position invariance part of the EEP and are tied to the possible spatial variation of the fine-structure constant α, a parameter central to quantum electrodynamics.

- BIOLOGICAL PHYSICS

The current focus on biology as the discipline that can have a dramatic scientific, social, and technological impact on life in the 21st century has brought forth an important challenge and opportunity to the Fundamental Physics community. Specifically, close coordination between the Fundamental Physics and Fundamental Biology communities will facilitate the solution of biological questions and the determination of the significance and applications of these solutions. At our present level of understanding, we lack the knowledge to directly link atomic and molecular processes to the dynamics and behavior of biological molecules and cells; we also lack an understanding of the development and control of complex biological networks. The sequencing of the human genome and other organisms is just the first step in a deep understanding of biological systems and their evolution. There are three basic connections between the new developments in biology and the Fundamental Physics Program: 1) the techniques and technology of fundamental physics can make substantial contributions to our understanding of biological phenomena; 2) the subtle yet important interactions between bio-molecules and cells are easily influenced by many aspects of gravity, either directly or indirectly through hydrodynamics; and 3) the developmental and functional cycles of organisms can be altered in the space environment where spatial and temporal symmetry-breaking effects found on earth are absent. In all these areas there are questions of fundamental physics that must be addressed before a deep understanding can be achieved.

Some examples of issues of interest to NASA in the area of biological physics include the study of biological clocks, circadian rhythms, and their underlying chemical oscillators, forced and unforced; problems in developmental biology such as symmetry-breaking in morphogenesis; bio-fluid dynamics, cellular motility, and chemotaxis in the absence of gravity; directed evolution in space coupled with genetic analysis; physics of biologically relevant colloidal suspensions, sedimentation, and aerosols; and physics of micro fluidics, miniaturization, and micromanipulation in biological systems.

- TECHNOLOGY DEVELOPMENT

This NRA also solicits speculative high payoff technology development activities that could enable new microgravity fundamental physics investigations to be performed in the future. Successful proposals are expected to be highly innovative and will aim to bring technology from the conceptual stage (readiness level 0 to 1) through to feasibility verification at the prototype laboratory stage (readiness level 3 to 4). With this solicitation, NASA is particularly interested in technology developments that in one way or another are targeting the use of coherent quantum phenomena. Examples of technology developments that fall into this category are techniques based on quantum fluid behavior, such as superfluid helium gyroscopes; techniques based on atom interferometers; and techniques based on superconductivity. Emergent nano-scale technologies based on laser cooling and trapping techniques, such as atoms on a chip and nano-laboratories, are also considered as high payoff technologies. The potential for interdisciplinary use of the technology will be an important selection criterion.

V. HARDWARE AND FACILITY DESCRIPTIONS

A list of hardware facilities and diagnostic capabilities available or planned for use in the Microgravity Fundamental Physics program is given below. Additional details can be found in the Bibliography section.

A. LOW TEMPERATURE MICROGRAVITY PHYSICS FACILITY (LTMPF) AND INSTRUMENT INSERTS

The LTMPF is a complete low temperature laboratory to be attached to the Exposed Facility of the Japanese Experiment Module on the International Space Station. The facility can support two instruments operating simultaneously. Each instrument can accommodate one or more investigations. A superfluid helium dewar maintains a base temperature pre-selected at between 1.6 K to 2.0 K for a period of approximately five months for the instruments. The facility will be launched approximately every 2 years with new instruments installed. The first flight is tentatively scheduled for 2005.

Each instrument consists of a thermal-mechanical platform (a probe) to which the experiment unique cells and sensors are attached. Each probe can have several stages of isolation platforms with separate temperature regulations on each stage to provide the maximum temperature stability. The total size available for both instruments is a cylindrical volume of 19 cm in diameter and 70 cm long. The total allocated weight for both sets of experiment hardware attached to the probes (but excluding the probe mass) is 12 Kg or less.

Electronics are built on the modular VME chassis with up to 35 slots for standard or custom-built electronic boards that can be reconfigured for each flight. Ultra high-resolution temperature and pressure sensors have been developed based on SQUID (Super-conducting Quantum Interference Devices) magnetometers. The LTMPF accommodates up to 12 SQUIDs shared between the two instruments. Other existing measurement techniques include resistance thermometers, precision heaters, capacitance bridges, precision clocks and frequency counters, modular gas handling systems, and optical access capability. An onboard flight computer controls all facility and instrument electronics, interfaces to the ISS, command, telemetry, and data storage during on-orbit operations.

Several layers of magnetic shielding are built into the instruments to protect the experiments from on-orbit variations in the magnetic field environment. Vibration and radiation monitors will provide experimenters with near real-time data. The main concern from charged particles is the heating they cause on the experimental cells and sensors. The estimated heating levels range from a fraction of a pico-watt per gram of material to many orders of magnitude higher heating levels, depending on the charged particle environment at that particular orbit location.

Additional information is available in the Bibliography section for investigators interested in the capabilities of the instrument inserts. NASA has an interest in allowing the use of these instruments to accomplish guest investigations on the ISS once the primary investigations, for which the instruments have been built, have gathered most of their data. Such collaborations need to be coordinated with the principal investigator responsible for developing the instrument in the first place. Please contact representatives at JPL for additional information about the use of existing instruments for guest investigations.

B. LCAP HARDWARE

There are currently two LCAP flight investigations under development by NASA. These are the Primary Atomic Reference Clock in Space (PARCS) tentatively scheduled for launch in 2005, and the Rubidium Atomic Clock Experiment (RACE) tentatively scheduled for launch in 2008. These experiments will feature laser-cooled atomic clocks and will carry out a variety of tests of general relativity theory. In addition, NASA is studying two additional investigations for potential flight aboard the International Space Station after the clock experiments have been flown. These experiments propose to study Bose-Einstein Condensation and perform experiments with an atom interferometer in space. To support these space flight experiments, a variety of technologies will be developed. The goal is to provide investigators with much of the same capability in space that they currently have in ground-based laser cooling experiments. A number of specific hardware packages are currently under development or are planned for development in this program.

Please consult the Bibliography section for additional details, or contact representatives from JPL for information.

GROUND-BASED FACILITIES and DIAGNOSTICS CAPABILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. NASA operates two drop towers at the Glenn Research Center (GRC) and parabolic flight research aircraft for use by investigators in this program. Please contact NASA for additional information.

NASA has adapted or developed a number of advanced techniques and technologies for microgravity fundamental physics research. Some of these techniques, such as high-resolution thermometry, SQUID readouts, and advanced thermal control systems, have already been successfully used in flight. Information about these technologies is available upon request.

VI. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

Starting with this NRA, NASA plans to issue NRAs annually instead of biennially as in the past. For budget planning purposes, NASA is planning to fund up to 6 highly meritorious flight experiment definition proposals from proposals submitted to this NRA (at a typically level of about $200,000 per year) and approximately 15-20 ground-based study proposals for those judged to be highly meritorious (at an average of approximately $100,000 per year) for up to 4 years. The initial fiscal year (FY) 2003 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA/JPL meetings (for a flight investigation, roughly 8 meetings per year with NASA/JPL should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead.

A complete schedule for the receipt and review of proposals to the Microgravity Fundamental Physics program is:

Notice of Intent Due: February 26, 2002

Proposal Due: April 12, 2002

Final Selections: September 2002

Funding commences: No sooner than October 2002
(dependent upon length of the procurement process)

VII. BIBLIOGRAPHY

Bibliography and World Wide Web sites that may provide useful information are

1. Physical Science Division general information: http://spaceresearch.nasa.gov/

2. Physical Science Division Tasks and Bibliography:
http://peer1.nasaprs.com/peer_review/taskbook/micro/mg00/mtb.cfm

3. Jet Propulsion Laboratory Fundamental Physics Information:
http://funphysics.jpl.nasa.gov/

4. The Proceedings of the NASA/JPL 1998 and 2000 Microgravity Fundamental Physics Workshop, JPL D-18442 and JPL D-TBD

5. Fundamental Physics in Space Roadmap, JPL 400-808, April 1999:
http://funphysics.jpl.nasa.gov/technical/library/roadmap.html

6. Jet Propulsion Laboratory Low Temperature Microgravity Physics Experiments Project:
http://funphysics.jpl.nasa.gov/technical/ltcmp/ltcmp-space.html

7. Jet Propulsion Laboratory Laser Cooling Activities: http://horology.jpl.nasa.gov/lcap/

8. Fundamental Space Biology Program general information and program contacts:
http://spaceresearch.nasa.gov/research_projects/spacebiology.html

Questions about this program element may be directed to the Microgravity Fundamental Physics Enterprise Scientist:

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APPENDIX F
NRA 01-OBPR-08

MATERIALS SCIENCE: RESEARCH OPPORTUNITIES

I. INTRODUCTION

In order to work within the limited space available in this NRA, the description of the materials science program provided below is a condensed version of that found in previous Materials Science NRAs and the discipline document. For the full text of the previous Materials Science NRA with the complete description of the program, please refer to http://research.hq.nasa.gov/code_u/dynamic.cfm?op_fy=1998

NASA has supported research in microgravity materials science for over three decades. An extensive research program supports computational, theoretical and experimental investigations in ground-based laboratories. A number of investigations are conducted using materials science research apparatus built to take advantage of the limited low gravity test times available in ground-based facilities such as the drop-towers at the NASA Glenn Research Center, or NASA's parabolic low gravity flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on materials processes and phenomena. While the materials science discipline has historically focused on research themes that benefit from access to long duration, high quality microgravity conditions, as the Microgravity Research Division evolved into the Physical Sciences Division, new tasks and research directions have been added that support NASA's crew health and safety responsibilities and NASA's exploration goals.

The NASA microgravity materials science program currently supports research in a broad range of areas that can be categorized in two orthogonal ways. The program has previously been described in terms of the class-like behavior of materials. Using this approach, the materials systems being investigated included electronic and photonic materials, glasses and ceramics, metals and alloys, and polymers and nonlinear optical materials. Alternatively, the Materials Science Discipline Working Group (DWG), an advisory body to NASA's Physical Sciences Division (PSD), has identified research areas, classified in terms of fundamental physical and chemical phenomena, that it believes would benefit from access to long-duration, high-quality microgravity conditions. Also included in the recommended research areas are those activities that the DWG believes are required to fully realize the potential of microgravity research (e.g. process modeling, materials characterization, etc.). The recommended research areas are: (1) Thermodynamics and kinetics of phase transformation; (2) Theory, modeling and experimental control of microstructure and defect formation; (3) Interfacial phenomena; and (4) Measurement of relevant material properties. The PSD has endorsed these recommendations and each of these areas is discussed in the sections that follow.

In addition to these areas of Materials Science, research in areas that support NASA's exploration goals is a priority. Specifically, these are radiation shielding appropriate for long-duration lunar or Mars missions, and the effects of gravity on the materials processes necessary to convert resources found on other bodies of the solar system into usable commodities. **Radiation shielding research was solicited very recently in NRA 01-OBPR-05. Although research addressing this topic will not be considered in this NRA, radiation shielding remains of significant interest to NASA and research supporting this subject will be solicited in future NASA Research Announcements.**

II. PROGRAM RATIONALE

Materials science plays a key role in virtually all aspects of the nation's economy.

While the ability to process materials to yield a given set of properties is clearly beneficial to humankind, the ability to produce a certain structure, and hence materials properties, is not yet at hand. Advances in materials science benefit a wide range of applications where materials are important as well as other areas of research that depend on advances in materials science as a basis for their continued progress. Long-duration microgravity is an important tool for establishing quantitative and predictive cause-and-effect relationships among the structure, processing, and properties of materials. Establishing, understanding and using these relationships are important elements in achieving increased international competitiveness.

The importance of materials processing lies in the understanding that the properties of most materials are dictated by the microstructure of the material, i.e. the morphology, size, spatial distribution, and chemical composition of the material's constituent phases, as well as internal defects.

Materials science deals with the relationships between the processing, structure, and properties of materials. Thus, if the relationship between processing and microstructural development is well understood, then first-principles design of a material with desired properties can indeed be realized. This design of materials is occurring today to a limited extent by applying a fundamental understanding of materials at the atomic, molecular, mesoscopic, and macroscopic levels. Nevertheless, a fully predictive model of the relationships between processing techniques and the microstructure of a material remains an elusive goal. Microgravity offers a unique environment that can be used to extend our present understanding of materials processing in ways that are not possible in terrestrial laboratories.

Many of the techniques used to process materials are strongly influenced by the presence of a gravitational field.

For example, during the formation of a solid phase from a fluid, as is the case during crystal growth and solidification, gravitationally driven convection of the fluid is probable. This fluid flow can alter the spatial distribution of impurities in the liquid and resulting solid, induce structural defects in the crystal, and, due to the complexity of the flows that are possible, make the results of crystal growth and solidification experiments performed on earth difficult to interpret. The presence of a gravitational field also can lead to sedimentation when two phases have different densities and at least one phase is a fluid. This sedimentation can lead to unwanted coagulation of the minority phase, as is the case during phase separation in certain polymer blends and in the colloidal processing of ceramics. A microgravity environment thus offers new opportunities to develop a deeper understanding of the relationships between many materials processing techniques and the resultant microstructures and materials properties.

The technological applications of importance to this discipline are quite broad.

They range from directional solidification and crystal growth to the production of ceramic powders. Applications of materials research serve the needs of the Nation as well as supporting NASA's mission. Research results have been used by industries as diverse as defense, steel, machine tools, sporting goods, electronic materials, and optics. With new research thrust areas in biomaterials and radiation shielding, results will support NASA's unique responsibilities for crew health and safety, and potentially benefit the health and well being of the American public.

III. CURRENT PROGRAM CONTENT

The Materials Science DWG's recommendation for the key elements of the supporting scientific knowledge base underpinning these process technologies are (listed in descending priority)

- Thermodynamics and kinetics of phase transformations (e.g., mechanisms of phase selection, oriented amorphous materials, and crystallization of amorphous materials)
- Theory, modeling, and control of microstructure and defect formation (e.g., studies of morphological evolution, growth-induced defect formation, aerogels and foams, colloidal and sol-gel processing)
- Interfacial phenomena (e.g., wetting behavior, self-assembly mechanisms)

Along with the knowledge base, a database provided by the quantitative measurement of relevant thermophysical properties is of high priority. These data are of paramount importance for precise modeling and interpretation of experimental phenomena.

Nucleation And Metastable States

In order for a material to transform to a more ordered phase (vapor to liquid or solid, and liquid to solid), it is necessary to first form an aggregate or cluster of molecules above a critical size to initiate the process. Such an aggregate may form on a foreign surface, such as a container wall or an inclusion (heterogeneous nucleation), or may form spontaneously from random internal fluctuations (homogeneous nucleation). Homogeneous nucleation can occur only if the melt or vapor is cooled well below its normal phase transformation temperature without solidifying. Heterogeneous nucleation will almost always occur first if there are any impurities that can act as nucleation sites. Understanding and being able to control nucleation is extremely important in materials processing.

If solidification is rapid enough, the atoms simply do not have time to arrange themselves in their lower energy or equilibrium configuration and metastable crystalline or amorphous phases can be produced. A metastable phase can have a different crystalline structure than the stable equilibrium phase, and this can greatly alter its physical properties. Another example of a metastable state is an amorphous phase. It may be thought of as a liquid structure, which lacks long-range crystalline order, frozen in place. Glass is an example of an amorphous solid. Amorphous materials are highly resistant to chemical attack because there are no crystalline grain boundaries, sites that are particularly susceptible to chemical reactions.

Prediction And Control Of Microstructure (Including Pattern Formation And Morphological Stability)

The microstructure developed during processing plays a crucial role in determining the properties of a material. Since different microstructures can be developed in a given material by changing processing conditions, it is important to understand how the changes in processing conditions influence the fundamental physics of microstructure formation. This knowledge is required for the design of processing conditions to develop a specific microstructure that gives optimal properties to the material. A proper design of microstructure involves the selection of stable or metastable phases and the appropriate morphology of the selected phase. Thus, understanding of the fundamental physics and chemistry that control the selection of phases, as well as microstructures, is critical to improving our ability to tailor microstructures to obtain optimal properties in a given material.

Some critical, unresolved theoretical problems in microstructure selection are to understand the role of processing conditions in (1) selection of stable or metastable phases, in which both the nucleation and the growth play important roles; (2) interface pattern evolution producing planar, cellular, dendritic, eutectic, or layered microstructures in a given alloy; and (3) development of scaling laws which quantitatively relate the microstructural length scales with processing conditions. These characteristic scales, for a given phase and given microstructure, are related to the mechanical properties of the material. Convective flows are unavoidable in Earth's gravity since density gradients due to lateral thermal and solute gradients cause convective motion of the fluid, making it impossible to test and refine the existing theoretical models and to quantify the importance of convective effects in ground-based solidification processing.

Phase Separation And Interfacial Phenomena

It is clear that a consideration of interfacial phenomena is common to numerous materials processing technologies. While limited studies of these interfacial effects are possible on Earth using density-matched immiscible systems, even in these systems, perfect density matching is possible only at a single temperature. Therefore, a microgravity environment provides a unique opportunity to study and quantify surface energy phenomena in order to promote more effective materials processing both on Earth and under microgravity conditions. A microgravity environment also provides a unique opportunity to measure the interfacial properties required to predict and control many materials processing phenomena.

The temperature and composition dependence of surface energy may also cause mixing in single-phase liquids. Convective flows driven by surface energy forces can be similar in magnitude or even greater than those induced by gravity. When temperature gradients are large, such as in welding, these flows can be very rapid, and their quantitative understanding is critical for modeling the shape of weld pools. Surface tension is a function of both temperature and composition, so that a gradient in either will drive flows. Fluid flow driven by variations in the surface tension along a free surface is called Marangoni convection. Usually, Marangoni convection is obscured by density-driven convective flows.

Transport Phenomena (Including Process Modeling And Thermophysical Properties Measurement)

All of the important phenomena that determine materials structure and properties during processing are controlled by heat, mass, and momentum transport. For each of these effects, the nature of the transport is determined by the relative importance of convective and diffusive transport. Whereas the system response is controlled by materials properties when diffusive effects are dominant, the system response is controlled by processing conditions when convective effects dominate. Microgravity provides a unique environment in which the relative importance of convective and diffusive transport can be controlled by the experimenter. Convective flows originate in solidifying systems because the many thermophysical properties vary with both composition and temperature. It is often desirable to suppress this convection, producing materials under purely diffusive conditions. To accomplish this requires a comprehensive understanding of transport processes.

Most of the process models developed to date focus on either macroscopic phenomena, such as fluid flow, or microscopic behavior, such as atomic attachment kinetics. Additional model development is needed to couple transport phenomena with microstructure formation models that are truly multiscale in dimension and time. In addition, it is now recognized that transient and oscillating acceleration in an orbiting spacecraft, so-called g-jitter, can strongly impact experimental conditions. Such phenomena can only be examined by comprehensive modeling in conjunction with experiments. Extension of these models to evaluate, in detail, the sensitivity of proposed microgravity experiments to g-jitter will continue to be a significant benefit in design of equipment for space experiments.

A serious deficiency in the ability to model materials processing is the lack of accurate thermophysical property data for most materials in the molten state. This is a problem not only for scientists modeling microgravity experiments, but for many industrial researchers who are using process modeling for terrestrial processes. The lack of high temperature thermophysical data is partially due to the extreme difficulty of making accurate measurements on melts in terrestrial laboratories.

Crystal Growth, And Defect Generation And Control

Temperature gradients in the melt are unavoidable during directional solidification of materials such as semiconductors. Furthermore, in growth from solutions, segregation of primary constituents, and to a lesser extent impurities, produce compositional variations in the melt. Under most processing conditions on Earth, the resulting density gradients yield significant buoyancy-induced convection that gives rise to property variations on both macroscopic (e.g., axial and radial segregation) and microscopic scales (e.g., point defect density fluctuations). These gravity-induced flows can produce local thermal and compositional variations at the growth surface, which in turn introduce defects into the solid with variable pattern, type, and number density. Another source of defects is the container wall, which can introduce strain and impurities into the crystal. The number and distribution of these defects, superimposed on macroscopic variations, then influence, often strongly, the performance of devices manufactured on or in these crystals. Indeed, the inability to control the defect structure of bulk crystals has led to the need for epitaxial thin films to improve the quality of semiconductor devices. It is clear that a better understanding of the mechanisms of defect generation would help in devising processes to control them. The space laboratory with variable acceleration vector has proven useful to improving our understanding of the crystal growth process.

Extraterrestrial Processes And Technology Development

Understanding of the fundamental role of gravity, in the space environment in chemical and physical systems is needed to achieve breakthroughs in science and enabling technology and will be required should a national mandate for human exploration exist. The focus of the PSD program in NASA's exploration mission is to foster fundamental understanding, building a foundation of knowledge that can be applied to both Earth- and space-based technologies.

Gravity plays a dominant role in many of the systems, processes and technologies that are needed to achieve the exploration goals of NASA. There are many specific scientific problems and issues that must be addressed prior to optimizing designs or developing more efficient systems for extraterrestrial exploration. These include physical and chemical processes in the areas of spacecraft systems, life support systems, and use of in-situ resources and power generation in extraterrestrial environments. Fundamental research is required to develop scaling laws for ranges of gravity levels between the microgravity environment of interplanetary travel to the partial gravity on Mars (3/8g) or the Moon (1/6g). Many areas of materials science research directly impact systems required for extraterrestrial exploration. As a result research is sought to help answer fundamental questions underpinning the relevant technologies.

In Situ Resource Utilization (ISRU)

Robust and energy efficient processes using local materials and resources are necessary to enable safe, productive, and cost effective human exploration of the inner solar system. Fundamental studies would yield a non-empirical approach to process development and design, thus generating support technologies independent of the process chosen for actual manufacturing to imbue flexibility and efficiency in the designs.

ISRU is a rapidly developing area relevant to exploration of other bodies in the solar system. Due to the cost constraints associated with transporting all of the necessary resources for a sustained visit and return trip from either the Moon or Mars, utilization of natural resources at the landing site is receiving strong consideration. Basic physical and chemical methods will be applied to process local resources into usable commodities. The focus of activities of the materials research community must be to develop an understanding of these processes in non-Earth environments. Examples of local resource utilization related physical and chemical processes include lunar derived oxygen and metals production from regolith (soil), creation of bricks from regolith for radiation protection and structures fabrication, and energy conversion and storage.

IV. FUTURE DIRECTIONS OF THE PROGRAM

The materials science program is in the process of being redefined. Recommendations for new directions are being formulated by the National Research Council's Committee on Microgravity Research (CMGR). In addition, workshops have been conducted soliciting new directions for materials research in electronic materials, radiation shielding, biomaterials, and materials science for advanced space propulsion systems. Results of the workshops on radiation shielding, and biomaterials were used to formulate the recent solicitation, NRA-01-OBPR-05, Materials Science: Ground-based Research Opportunities in Biomaterials and Radiation Shielding. Results of the Materials Science for Advanced Space Propulsion Workshop were used to structure the research solicitation described in Appendix G of this NRA. This topic represents a new initiative and future direction for the Materials Science Program.

The future directions for materials science research are based on the CMGR report on Phase I of the ongoing study: "The Mission of Microgravity and Physical Sciences Research at NASA," released December 12, 2001, and a workshop on "New Directions for NASA's Electronic Materials Program" conducted at the Twelfth American Conference on Crystal Growth and Epitaxy held August 14, 2000 in Vail Colorado.

The CMGR identified four new areas for research in the Physical Sciences Division. 1.) nanoscale materials and processes, 2.) biomolecular physics and chemistry, 3.) cellular biophysics and chemistry, and 4.) integrates systems for Human Exploration and Development of Space (HEDS). The Committee selected a few examples of broad research topics within each of the new areas (listed below). They indicated that many more suitable topics would likely emerge from the research community. It should be noted that, though many of the examples are germane to the materials science discipline and its fundamentally interdisciplinary nature, others are more suited to other disciplines within the Physical Sciences Division.

- Nanoscale Materials and Processes
  - Nanoparticle formation
  - Integrated nanomaterials
  - Micro- and nanoflluidics

- Biomolecular Chemistry and Physics
  - Proteins in cofined space
  - Energy storage and chemically driven nanosystems
  - Smart and self-healing materials

- Integrated Systems for HEDS
  - System integration of nanoengineered particles and devices

The workshop on "New Directions for NASA's Electronic Materials Program" identified the following areas where new research would be valuable:

- Multiphase systems processed from fluids

- Understanding wetting and dewetting during crystal growth (detached solidification)

- Nanostructured materials

- Electronic materials for advanced sensors

- Fluid transport related defect generation
- Process modeling and thermophysical property determination
- Novel materials and processes

V. HARDWARE AND FACILITY DESCRIPTIONS

A. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the MRD materials science program include an array of specialized laboratory apparatus, such as laboratory equipment (i.e. furnace systems, special diagnostic tools and equipment, etc.), an evacuated drop tube at MSFC, a drop tower at GRC, and parabolic flight research aircraft. A variety of specialized test apparatus have been constructed and used to conduct a wide range of materials science research. In general, these apparatus have been developed to accommodate specific individual investigator's requirements. In addition, other hardware and facilities have been developed which have the potential for use by investigators. Investigators should denote any additional facilities needed for their research, and such facilities, if available, can be made accessible on a limited basis.

5.18 SECOND ZERO GRAVITY FACILITY

The 5.18 second Zero Gravity Facility has a 132 meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments with hardware weighing up to 450 kilograms are mounted in a 1-meter diameter by 3.4-meter high drop bus. Residual acceleration of less than 10^{-5} g is obtained.

PARABOLIC FLIGHT RESEARCH AIRCRAFT

The aircraft can provide up to 40 periods of low gravity for 22 second intervals during each flight. The aircraft accommodates a variety of experiments and is often used to refine spaceflight experiment equipment and techniques and to train crew members in experiment procedures, thus giving investigators and crew members valuable experience working in a low gravity environment..

LOW GRAVITY AIRCRAFT MATERIALS SCIENCE APPARATUS

1. Automated Directional Solidification Furnace (ADSF)

This furnace is based on a prototype of the Grumman ADSF that flew sounding rocket and Space Shuttle experiments with Mn–MnBi alloys. The furnace uses a basic Bridgman furnace configuration. It been optimized for use in parabolic flight aircraft and has been fitted with a water spray interfacial quench device.

2. Isothermal Casting Furnace (ICF)

The ICF is designed for multidimensional solidification (bulk casting) during a single aircraft parabolic maneuver. The sample thermally soaks at a predetermined temperature for a specific length of time and is then quenched by a stream of helium gas during the low gravity period of the parabola.

3. Quench Furnace With X-Ray

A Quench Furnace with X-Ray is also available for ground-based low-gravity research at GRC. This three zone, end chill, directional solidification furnace with a water quench can reach a maximum temperature of 700°C. The liquid-gas and solid-liquid interfaces are recorded using x-ray scanning and high resolution CCD camera.

B. SPECIALIZED GROUND BASED RESEARCH CAPABILITIES

In addition to the specialized ground based microgravity capabilities such as drop tubes and drop towers, and parabolic aircraft, NASA is able to support selected Principal Investigators with state-of-the-art laboratory equipment, sample preparation facilities and computing support. These facilities are offered on an as available basis, through the Microgravity Science and Applications Division of the Marshall Space Flight Center, who have available trained personnel to assist all experimenters.

MSFC ELECTROSTATIC LEVITATOR (ESL)

A new containerless electrostatic levitation research facility for materials and fluids has been established at MSFC, derived from a system donated by LORAL. The facility uses electrostatic forces to levitate specimens in a vacuum chamber, then a high power infrared laser heats and melts these specimens. A 60 W YAG laser is available for metallic specimens and two 50 W CO_2 lasers are available for oxides and ceramic specimens. By isolating a material from all but its radiation environment, the disturbing influences of container walls and impurities are removed. The electrostatic forces will levitate a wide variety of materials: conductors, semiconductors, and insulators.

Specimens are typically spheres, 2-3 mm in diameter. Once a specimen is levitated and melted, the ESL can apply a range of measurement techniques to measure the material's thermophysical properties, such as specific heat capacity, density, surface tension, viscosity, and optical emissivity, all as functions of temperature. At a given temperature, density is measured through analysis of a digitized silhouette image, and viscosity and surface tension are obtained from the frequency and rate of decay of shape oscillations.

More details are available at: http://esl.msfc.nasa.gov/

HIGH MAGNETIC FIELD SOLIDIFICATION FACILITY

Built at MSFC, the High Magnetic Field Solidification Facility includes two 5 Tesla superconducting magnets each with a vertical, 25 cm diameter room temperature bore. Resistance heated tubular furnaces capable of temperatures to 1200°C with bore diameters up to 2.5 cm are available and include thermal control and translation mechanisms.

STEREO IMAGING VELOCIMETRY (SIV)

A system of hardware and software has been designed to allow acquisition of three-dimensional vectors describing flow simultaneously throughout an experimental volume. Used for ground-based and flight experiments, the quantitative results may be compared directly with numerical or analytical predictions of flow velocities. The system requires a transparent fluid seeded with particles large enough to be viewed as a full pixel on a video screen.

COMPUTATIONAL CAPABILITIES

NASA has the capability to provide the research community numerical modeling analysis (such as SINDA, HEATRAN, COSMOS, FIDAP) of material/fluid flows as influenced by thermal gradients, concentration gradients, surface tension, magnetic fields, gravitational acceleration, g-jitter and other driving forces. The emphasis is on physically based models giving quantitative flow descriptions. The facilities have commercial and specialized software operating in a workstation environment with access to mainframes.

X-RAY MICROSCOPE

This instrument is designed to view in situ solidification of thin, light samples with high resolution. The technique uses direct x-ray projection from a point source. The divergent beam passes through the sample. With a furnace permitting solidification to within a few mm of the x-ray source, in situ interfaces can be visualized at a resolution of 30 µm.

SPREADING RESISTANCE MEASUREMENT

A Solid State Measurements model 150 spreading resistance apparatus is available at MSFC. To use this instrument an investigator is expected to provide his/her own set of measurement probes.

OPTICAL AND ELECTRON OPTICAL MICROSCOPY LABORATORY

The equipment of a modern microscopy laboratory is available, including:

1. A Zeiss Axioplan 2 optical microscope equipped for reflection/transmission microscopy with Nomarski interference contrast, dark field, image processing, filar eyepieces for precise measurement, and automated and large stage capabilities. In addition, an older Zeiss Ultraphot III optical microscope with an infrared camera system is available.
2. A Zeiss scanning electron microscope, model DSM 960, equipped with a Link energy dispersive x-ray analysis system and beam controlling software. The collection of quantitative chemical analysis data can thus be automated. The system also includes an OPAL electron back scatter detector, which can be programmed to determine grain orientation over large sample areas. Other accessories include a cold stage and electron beam induced current imaging (EBIC).
3. A JEOL JXA 8900R electron microprobe analyzer equipped with three spectrometers for wavelength dispersive x-ray analysis, and a Noran energy dispersive x-ray system. Both of these systems permit quantitative light element determination. The microprobe is fitted with a large specimen stage.

X-RAY DIFFRACTION LABORATORY

X-Ray diffraction capabilities include a Philips Materials Research Expert Diffractometer, which operates on a Rigaku rotating anode x-ray generator. This instrument is available for the measurement of rocking curves and for reciprocal lattice mapping. Other x-ray equipment available includes a Rigaku powder diffractometer, a Blake Industries Laue camera and a Bede double axis diffractometer.

V. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

Please note that we plan to issue NRAs annually instead of biennially as in the past. Accordingly, for the purposes of budget planning, we have assumed that the Physical Sciences Division will fund approximately 25 proposals from those judged to be highly meritorious for ground-based research in materials science. The level of award for materials science research is expected to be a maximum of $150,000 per year for four years. The initial fiscal year (FY) 2003 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year. Specifically, the resources required for the first year should not be overestimated.** The proposed budget for ground-based studies should include researcher's salary, travel to science and NASA meetings, other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRAs similar to this NRA will be issued, and funds are planned to be available for additional investigations.

All proposals submitted in response to the Materials Science for Advanced Space Propulsion program are due on the date given below by the close of business (4:30 p.m. ET). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

Notice of Intent Due:	April 15, 2002
Proposal Due:	June 3, 2002
Final Selections:	December 2002
Funding Commences:	No sooner than April 2003

(dependent upon length of the procurement process)

VI. BIBLIOGRAPHY

Documents and Web sites that may provide useful information to Investigators are listed below.

1. Office of Biological and Physical Research Homepage at NASA Headquarters, http://spaceresearch.nasa.gov

2. Microgravity Research Program Office Homepage at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov

3. NASA Microgravity Materials Science Conference 2000 Proceedings, NASA Conference Proceedings CP-2001-210827, March 2001.

4. Microgravity Science and Applications Program Tasks and Bibliography, 2000, (and prior editions) http://peer1.nasaprs.com/peer_review/taskbook/micro/mg00/mtb.cfm

Questions about this program element may be directed to the Enterprise Scientist for Materials Science:

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ACRONYM LISTING

ADSF	AUTOMATED DIRECTIONAL SOLIDIFICATION FURNACE
ESL	ELECTROSTATIC LEVITATOR
GRC	GLENN RESEARCH CENTER
ICF	ISOTHERMAL CASTING FURNACE
ISS	INTERNATIONAL SPACE STATION
JPL	JET PROPULSION LABORATORY
MRPO	MICROGRAVITY RESEARCH PROGRAM OFFICE
MSFC	MARSHALL SPACE FLIGHT CENTER
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NRA	NASA RESEARCH ANNOUNCEMENT
PI	PRINCIPAL INVESTIGATOR
SCN	SUCCINONITRILE
SIV	STEREO IMAGING VELOCIMETRY

APPENDIX G
NRA 01-OBPR-08

SPECIAL FOCUS THEME:
MATERIALS SCIENCE FOR ADVANCED SPACE PROPULSION
RESEARCH OPPORTUNITIES

I. INTRODUCTION

- BACKGROUND

Our nation's space program faces enormous challenges as we seek to achieve dramatic improvements in safety and cost while expanding the frontiers of space far beyond those that could only be dreamed about in the past. Foremost among those challenges are two interrelated arenas: Space Propulsion and Materials Science. The physics of deep space travel dictates propulsion systems that will ultimately be far more efficient than the chemical systems in use today. These in turn will require materials with a wide range of mechanical, thermophysical, and thermochemical properties, many of them welll beyond capabilities of today's materials systems.

The process for space system development rarely demands direct, revolutionary advancements from one concept to the next. Such an approach would usually be doomed from the beginning, because space propulsion systems possess far too many technological dependencies. These technologies would have to be orchestrated in their development to concurrently converge at the point that they could be successfully synthesized to produce the revolutionary new system. More often, a "building block" approach is employed, in which scientific advancements evolve into new technologies, which are verified on a state-of-the-art system. Successful certification and incorporation of the new technology then redefines a state-of-the-art system, which in turn provides a testbed for further development. Thus, the process of space propulsion system development can be thought of as evolutionary, rather than revolutionary, and focused scientific developments can proceed at varying rates and schedules, provided only that they remain responsive to the "roadmaps" that are defined and updated by the system developers.

In response to the long-term needs of these system developers, a Workshop was conducted which brought together the full spectrum of organizations and expertise necessary to identify, develop, and prioritize basic research focal areas to address the materials science needs of advanced space propulsion systems. The individual and organizational constituency provided representation from the propulsion system customers for the materials research, the materials science community which will perform the research, and the materials scientists and technologists at the NASA laboratories who will serve as interfaces between the system level projects and the materials science community.

- OVERVIEW OF ADVANCED SPACE PROPULSION MATERIALS ISSUES: CUSTOMER IDENTIFIED NEEDS

This section provides background information that identifies and summarizes propulsion system customer needs. Section II defines the basic research solicitation scope.

Advanced space propulsion is an enabling element of the Advanced Space Transportation Program (ASTP), which includes Hypersonics, In-space Propulsion and Revolutionary Propulsion Research. The 3rd Generation RLV/Hypersonics Program envisions investments in concepts such as rocket based combined cycle, turbine based combined cycle, high speed propulsion/airframe integration technologies (scramjet) and long life, high thrust/weight ratio rocket propulsion. Dramatic increases in performance are sought, with attendant reduction in system weight, while also improving operability and safety. The time span for these developments is 20 – 25 years.

Improved system performance for in-space propulsion technologies will be pursued to provide new capabilities for space science and exploration, to reduce overall life cycle costs, to reduce propellant mass, and to significantly reduce mass fractions (30% to 75%). [Mass fraction is also known as inert-mass fraction, which is defined as the inert mass of the system divided by the sum of the inert mass and the mass of the propellant.] Expected benefits are reduction or elimination of the need for gravity assist (launch any year), shorter trip times, new vantage points and new destinations, and smaller launch vehicles (lower cost or more payload), which will enable sample return missions and outer planet orbiters. Technology priorities are derived from enterprise requirements. High priority technologies are aerocapture, solar electric propulsion (SEP) and nuclear electric propulsion (NEP). Medium priority technologies are SEP Hall thrusters, electric propulsion, advanced chemical propulsion (lightweight components), and ultra-thin solar sails. Identified high risk/high payoff technologies are plasma sails and momentum exchange tethers.

Emphasis for far term (>25 years maturity) propulsion research should be placed on selected areas leading to high payoff future propulsion technologies such as magneto-hydrodynamics (MHD), nuclear fusion propulsion, and high power (MW-class) electric thrusters.

Magnets are essential components of most advanced propulsion systems that utilize high specific energy concepts such as beamed energy/momentum, nuclear fusion and fission, and matter-antimatter annihilation. Ground-based magnet technologies are mature but too massive for flight systems. Exploratory research in flight weight magnet materials and research to improve processing technology is needed. The challenge is to achieve low-weight, large volume, high-field magnets. Some propulsion concepts using magnets are MHD bypass airbreathing engine, microwave lightcraft (containing a superconducting magnet), and nuclear MHD space power for electric propulsion and magnetically contained fusion reactor.

Aeroassist/aerocapture requires minimum mass and maximum size, which translates to very thin materials having very high tensile strengths at very high temperatures. High emissivity is also required to facilitate radiative cooling. Electric propulsion technologies require innovative materials for power system components (relays, batteries, capacitors, electronics, transformers, etc.), thruster body housings and coatings, power transmission line systems, propellant tanks (liner-less composite) and feed systems (valves, bellows, regulators), and electrical and thermal insulations. Electric propulsion components require very high temperature, erosion resistant electrode materials, low sputter-yield materials and efficient electron emitters. Thermal radiators require lightweight materials with innovative, functionally-graded coatings with high emissivity. Materials challenges for nuclear electric propulsion include refractory metals for space reactor applications (Mo and Mo alloys) and high temperature materials for dynamic conversion.

Advanced chemical propulsion requires materials and improved processing technologies to reduce mass of propulsion components such as feed systems, tanks, etc. Cryo-cooler development requires materials having high thermal conductivity and high heat capacity (Erbium alloys have shown promise), and oxygen compatible materials for tanks, mixer pumps and seals.

Solar thermal propulsion technologies require high temperature, lightweight materials. A solar absorber cavity requires hydrogen compatible materials that can withstand temperatures of 2000-3000K or higher, have low emissivity and high absorption for solar radiation, and be able to withstand 100 – 1000 thermal cycles. Candidate materials are rhenium, tungsten and their alloys; hafnium niobium carbide, carbon coated to resist hot hydrogen gas and advanced cermets. Typical candidate materials for primary solar concentrators and structural components, including inflatable structures, are polyimide materials and advanced polymers.

Bimodal nuclear thermal propulsion materials needs are reactor fuels (cermets – uranium oxide fuel in WC matrix with some Re alloying and operating in the temperature range of 2650 to 2900K; ternary carbides, e.g. U-Zr-Nb, for up to 3100K), coatings or hot hydrogen resistant materials for nozzle environments, and liquid hydrogen compatible cryotanks.

Tether materials need to resist damage from low earth orbit (LEO) space environment (especially atomic oxygen) and embrittlement due to exposure to electromagnetic radiation. There is a need for long life tether materials having high strength, fabrication flexibility, stability in LEO environment, and conductive coatings for LEO environment. Also needed are insulating materials with dielectric strengths, flexible enough to prevent damage and stable in LEO. Electrodynamic tethers need low electrical resistance and lightweight, high strength conductors. Cost effective fabrication technology must be developed.

Solar sails materials requirements are high temperature tolerance (up to 2000K), high emissivity, high tensile strength, good gamma ray and ultraviolet radiation tolerance, low coefficient of thermal expansion and sail fabric areal density of 0.5 grams per square meter. Plasma sails require lightweight magnets. Magnetic sails require a breakthrough in high temperature superconducting coils.

- PROGRAM RATIONALE

Advances in materials are required to enable propulsion systems under consideration for 3rd Generation RLV and also for those systems envisioned for In-Space Propulsion.

To address these needs, a new thrust area (Materials Science for Advanced Space Propulsion) is being established for the PSD Materials Science Program through the solicitation of

1. Basic research that is directly related to an important problem in advanced space propulsion and can be accomplished on a time scale such that the propulsion system would benefit from the results of basic research.
2. Research that would benefit from the unique advantages provided by long duration, high quality microgravity conditions. It is expected that the gravity dependent ground-based research would provide the foundation for future flight experiments.

Materials Science for Advanced Space Propulsion basic research proposals should include a section that clearly articulates the relevance of the research to NASA using at least one of the above criteria.

Based upon the results of the previously referenced workshop, the materials science program seeks to support basic research in the following thematic areas as related to advanced space propulsion. <u>Basic research needs have been identified in all but a few sub-topics. In these areas wherein fundamental research issues have not been explicitly stated, higher level characteristics and materials needs have been described. In all cases, a section of the proposal should be included that clearly articulates the relationship between the topic of basic research and the materials technology need as described in the particular section of this NRA.</u>

ENABLING MATERIALS: Current materials will not meet the challenging operational requirements and environments demanded of future high temperature and high energy systems involving chemical, nuclear, electro-magnetic, magnetic, solar thermal, and photonic propulsion.

The following critical materials needs associated with those systems were identified during the Workshop: materials for flight weight magnets, high temperature radiators, thruster materials, nuclear fuels and materials, high specific strength and stiffness materials, and solar sail materials.

<u>Materials for Flight Weight Magnets</u>: These materials have applications in magnetic confinement and as guideways in nozzles. They are absolutely enabling to a wide range of breakthrough propulsion systems, including plasma thrusters, fusion propulsion, electric thrusters, and magneto-hydrodynamic (MHD) accelerators. In the long term, they are required for anti-matter containment in systems that will utilize breakthrough physics principles.

The challenge is to achieve low weight, large volume, high field magnets, and requisite improvements in the strength of associated structural support materials. Common magnet systems have specific energies* on the order of 5 kilojoules per kilogram. The most advanced laboratory scale magnets presently can develop specific energies around 30 kilojoules per kilogram. The advanced propulsion systems noted above will require significant advances. Increases of at least another order of magnitude, or specific energies approaching unity, have been discussed, however, such improvements may ultimately be restricted by limited advances in the capabilities of the structural support materials.

*Specific energy is defined as: $E_{sp} = \frac{B^2}{2\mu} x \frac{V}{m}$

where: B = magnetic flux density
μ = permeability in space, a constant
V = volume of the magnetic system
m = mass of the magnetic system

Radiator Materials: Present heat pipe and lightweight radiator systems are limited to relatively low temperature (~700K) heat rejection. These systems are largely based on low temperature alloys using Al and Mg and compatible working fluids. Extending space propulsion to higher specific impulses, especially in the case of nuclear electric propulsion, would require significantly higher levels of heat rejection. In order to maintain a reasonable radiative surface area for high power heat rejection, it is necessary to develop heat pipes and radiator materials for high temperature operation for periods of time exceeding ten years. There are two temperature ranges of interest, 700K – 1000K and 1000K – 1400K. Research should include the interaction of the candidate lightweight materials with appropriate working fluids, and coatings or surface modifications for emissivity enhancement. The emissivity enhancements must maintain excellent stability in the high vacuum and radiation environment of deep space.

Thruster Materials: All electric propulsion systems exhibit two significant characteristics that must be addressed: electrode erosion and the need for improved electron emitters.

Electrode erosion is a performance-limiting phenomenon in grids, electrodes, and housings associated with magneto plasma dynamic (MPD) thrusters, magneto hydrodynamic (MHD) accelerators, and ion engines. Current state-of-the-art materials are metals and alloys, all of which experience sputter erosion, which reduces efficiency and shortens functional life. Materials are needed which will enable increasing functional life to greater than ten years of continuous operation.

Electron emitters include field emitters, hollow cathodes, and filaments. The present field emitter state-of-the-art allows operation at approximately 1 ampere per square centimeter. Research effort is required that will enable electron emission greater than 10 amperes per square centimeter for continuous operations exceeding ten years.

Nuclear Fuels and Materials: Nuclear power for in-space propulsion provides revolutionary improvement in weight, volume and specific impulse performance over conventional chemical propulsion systems. The power densities of nuclear fuel materials are more than 7 orders of magnitude higher than chemical fuels that are used in traditional space propulsion systems. Nuclear power is also used to generate electricity at very low specific mass (kg/kW_e), which is key to enabling technology for nuclear electric propulsion (NEP) concepts such as Lorentz force and ion thrusters. NEP reactors need to operate at lower temperatures (than NTP reactors) but for 20,000 to 100,000 hours. Generally, there are three capability levels: stainless steel clad fuels for 1050K operation, state-of-the-art; refractory clad fuels for 1340 – 1950K operation, near-term state-of-the-art; and higher temperature fuels such as graphites, carbides, or cermets for 2000 – 2500K operation. There is no hydrogen present, but the higher temperature fuels may be helium cooled and long life is required. Currently power levels in the 100 to 1500kW_e range are envisioned for electric propulsion. Nuclear fission reactions are the most realistic source of such power levels for in-space propulsion.

NEP fuels must have adequate fuel loading, temperature and burn up capability. Near-term interest centers around demonstrating uranium nitride-based fuel/clad systems operating at peak fuel temperatures of 1800K and peak cladding temperatures of 1700K, and on demonstrating uranium dioxide fuel/clad systems operating at peak cladding temperatures of 1900K. Of additional near-term interest are fuels with the fuel loading, temperature, and burn up capability necessary to help enable low power (<50 kW_e) systems with specific mass <25 kg/kW_e. Longer-term interest centers around high power systems (>1 MW_e) with a specific mass (< 10 kg/kW_e).

Significant improvement in nuclear thermal rocket lifetime and performance could be achieved by using nuclear fuels comprised of a solid solution of mixed uranium carbides and uranium-based ceramics dispersed in a refractory matrix (cermet). Since hydrogen is the propellant used in nuclear thermal propulsion systems, these fuels are required to be fully compatible with hydrogen at temperatures exceeding 3000K. In order to achieve optimum performance, the processing, characterization, and evaluation of mixed uranium/refractory carbides and cermet fuels is the key scientific challenge. Examples of mixed uranium carbides include uranium zirconium niobium carbide (U, Zr, Nb)C, where Nb could be substituted by Ta, Hf, or W. Traditional cermet fuel is comprised of uranium dioxide or uranium nitride in a tungsten matrix. Due to higher chemical stability and compatibility with tungsten, uranium zirconium carbonitride (U, Zr)CN, has potential to improve the performance of cermet fuels.

<u>High Specific Strength/Stiffness Materials</u>: Reduction in mass fraction is absolutely essential for the success of advanced space propulsion. The Hypersonics program requires a high thrust/weight ratio rocket engine and dramatic reductions in system weight without compromising operability and safety. For example, turbopumps for these propulsion systems have specific requirements: operation in high stress, shock, and vibration environments; and at high temperatures in the presence of oxygen (lightweight ceramic composite materials are good candidates). High strength and toughness materials able to be formed into complex shapes for pump housings are required. Clearly, materials having high specific strength/stiffness are needed. These materials will replace currently used materials for propulsion systems (chemical, nuclear, electric, and others) to reduce weight and to increase performance and operability (reusability). Depending on the application, these materials should be compatible with a wide range of fuels and environments, such as for nuclear propulsion application, and a wide range of temperatures. The current state-of-the-art technology for chemical propulsion includes heavy metal alloys such as Inconel 718 and Haynes 214, which cannot enable achievement of the required performance goals. Composite materials, such as metal, polymer, and ceramic matrix composites, could potentially be formulated with the required capabilities, but there is a need to improve our understanding of fundamental issues, such as matrix to reinforcement interface reactions, load transfer from matrix to fiber, and others.

<u>Other examples of high specific strength materials, and associated needs include:</u>

- Porous cellular materials – combine specific strength and thermal insulation
- Niobium-Molybdenum (Nb-Mo) alloys for applications at temperatures >2000K
- Carbon-carbon (C-C) for in-space propulsion.
- Insulating materials for space applications (both thermal and electrical)
- High efficiency power transmission lines – able to carry high currents without significant losses (Electric propulsion)
- Coatings to protect candidate materials (e.g. CMC) or parent material systems that are resistant to hostile environments and operational conditions
- Materials based upon single-wall nanotubes

<u>Solar Sail Materials:</u> Photonic sails, either solar or laser propelled, share common desirable properties. Specific material requirements are mission dependent, but in general these materials are required to be lightweight, robust, and resistant to space environmental effects.

Ultralightweight materials that are both robust to ground processing and tolerant to the effects of prolonged space environment exposure are required, in order to develop photonic sails capable of interstellar exploration. Current state-of-the-art is:

- Polymeric film, areal densities on the order of 5 g/m^2, can be readily manufactured
- Carbon fiber, areal density on the order of 3 g/m^2, has been made as a prototype

The targets are:

Sail materials with areal densities < 1 g/m^2, desirable to approach or be lighter than 0.1 g/m^2. In addition, the sail should possess the following characteristics:

- High tolerance to Space Environmental Effects
  - i. Low degradation of mechanical and optical properties after charged particle radiation dose >10,000 Mrad
  - ii. Low degradation of mechanical and optical properties after ultraviolet exposure equivalent to 20 years exposure to >1350 W/m^2 solar irradiance
  - iii. High temperature material, capable of withstanding the thermal and radiation environment at 0.25 astronomical units
- Optimized thermo-optical properties to allow efficient function during mission lifetime (i.e., high reflectance and high emittance using reflective photonic propulsion, high absorptance and high emittance using absorptive photonic propulsion)
- Robust to ground processing and handling
- Inherently free of wrinkles and creases after stowage
- Tailorable electrical conductivity to mitigate charging effects
- Possessing rip stop capability

ENABLING PROCESSES: Commensurate advances and innovations in materials processing are required to achieve the critical properties and characteristics that are enabling for future launch and in-space propulsion systems.

Requirements for process advancements to create capabilities for producing materials having the targeted application-specific properties were recognized at the workshop. To avoid redundancy, those requirements are not repeated in this sub-topic, but are implicitly included. A specific focal area described below, self-assembly and self-organization, was identified as a key challenge for designed/engineered materials, specifically as related to nano- and micro-scale materials.

<u>Self-Assembly And Self-Organization</u>: In the context of this research area, self-assembly and self-organization refer to the ability to use specific processing techniques in multi-component systems in order to produce desirable, often complex, arrangements of constituents. An example is the directional solidification of alloys in eutectic-type systems under conditions that lead to the coupled growth of a fibrous microstructure. The resulting *in-situ* composite that is produced has the appearance of a man-made composite with the exception that the fibrous reinforcement may be finer and more ordered than often can be accomplished by other means. This problem statement focuses on the use of *in-situ* processing techniques in order to produce materials with properties desired for space propulsion.

Current research has proven that smaller domain sizes often lead to the development of unique and highly sought-after characteristics. However, the ability to consistently produce self-assembled micro- and nano-scale structures has not been demonstrated, even though some microscale structures are in use. The full benefits of a systematic study in the nano domain size cannot be overemphasized. Unique combinations of properties that are usually considered self-exclusive should be achievable. This area demands further development. Additional work is needed on micron size self-assembled structures as well as where processing will likely be influenced by gravity. **As a result, microgravity conditions may be needed for both processing and mechanistic understanding. (See also next section)**

Solidification of multiphase mixtures requires improved theory and experimentation for understanding the behavior of eutectic, monotectic, and peritectic solidification. The use of solid-state transformations, including precipitation and eutectoid reactions to produce self-assembled structures, should also be investigated. In addition, as length scale decreases, current predictive models break down and utterly new and unexpected properties may result.

Research is required in several areas to address the needs in this category. These areas include

- Obtain a basic understanding of self-organizing processes
- Develop predictive models as they relate to structure, processing, and properties
- Develop materials with combinations of properties not found in nature or by conventional alloying

Examples of potential developments include production of self-assembled, nano-scale materials that exhibit unusual combinations of properties, such as high specific strength and high thermal and electrical conductivity. High melting temperature self-assembled nanocomposites could provide high temperature materials that are stable in propulsion service environment (air-breathing, nuclear, etc.).

RESEARCH ENABLED BY ACCESS TO SPACE ENVIRONMENT: Microgravity conditions may provide the necessary research environment to enable fundamental understanding of materials processing, properties measurement, and techniques required for on-orbit fabrication and repair.

Several research areas among the prioritized needs were identified at the workshop as having significant potential to benefit from experimentation in the microgravity environment. Those included materials processing and mechanistic understanding (noted in the prior sub-topic), measurement of key properties critical to advances in engineered materials and modeling (cited in the following sub-topic) and free-form fabrication, which is described below.

Free-Form Fabrication: Free-form fabrication typically involves the use of a powdered form of a material and a focused heat source to build a desired part or component in a layer-by-layer fashion. The resulting part can have mechanical characteristics almost identical to those of a part produced from a typical cast-form-machine approach. For the space program, free-form fabrication provides a venue for *in-situ* production of replacement parts during long duration missions, assembly, and repair. This capability to manufacture components during a mission will be an essential element to the human exploration and development of space.

Equipment designed for operation under 1-g conditions is currently available commercially that can create the following types of structures: rough steel parts, green ceramics that require high-temperature post processing, and traditional polymeric pre-forms. However, there is currently a limited capability to process highly reflective metals such as aluminum or copper. A significant research effort is needed to develop the techniques that will permit free-form fabrication in space as well as to characterize the products resulting from the use of these techniques. The obvious goal is to develop directly usable materials for space flight hardware.

Free-form fabrication will likely become a vital tool in repairing and replacing damaged components in space vehicles. However, in microgravity, the behavior of powder and molten materials is widely different from the ground. Both theoretical and experimental rheological studies are needed. An understanding of the influence of many variables and how they influence the process under microgravity conditions will be necessary. The areas for research will include:

- Basic research in material delivery systems for use in microgravity, e.g. feedstock (powder, liquid, wire) handling methods, powder recovery and reuse
- Understanding of solidification and liquid phase sintering in the microgravity environment
- Determining the influences of surface tension and wetting, and the effects of porosity
- Grain size distribution as influenced by material deposition
- Development of effective joining methods for use in the free-form fabrication process

- Determining the range of alloys producible with a limited number of constituents
- Microstructural control via manipulation of deposition parameters and/or heat treatment
- Materials science issues of weld pool properties in microgravity
- Production of functionally graded materials within a fabricated object

This effort may involve both experimental and theoretical work.

ESTABLISHMENT OF CORNERSTONE KNOWLEDGE: Characterization of engineered materials properties and advancements in predictive capabilities for materials modeling and design spanning length scales from nano- to macro-scale are required to develop and implement new materials into advanced space propulsion systems.

Development of fundamental knowledge of materials properties and behavior is important to the design and construction of materials for advanced space propulsion systems. Examples are thermophysical properties, thermochemical properties, and mass transport properties that would enable processes and fabrication such as self-assembly and self-organization. **Access to microgravity can be beneficial to research in this area. (See also previous section)**

Prediction and Verification of Materials Properties: Advanced space propulsion systems will require unique sets of materials properties to meet the challenges described in prior sections of this Appendix. In some cases, existing materials do not possess the required suites of properties, and therefore new materials will have to be developed to meet the requirements. It is not expected that these materials will be discovered; they will be designed specifically to meet the operating conditions, requirements, and environments of the target applications. Recent advances in materials modeling and advanced characterization techniques will have a significant impact on the timely discovery, development, and engineering application of materials for advanced space propulsion. The methods can be categorized by the materials properties which they address. The next section describes the status of the methods, and identifies research topics that are needed to permit them to make a significant impact on the propulsion problem.

- *Thermochemical Properties:* Nuclear propulsion systems will require new fuels to be consistent with mission requirements for space application. Current methods for computing the phase diagrams necessary to support this development effort are developed for industrial systems, such as for alloys of Al, Fe, Mg and Ti. Data are also available for dilute alloys of Si and III-V compounds for semiconductor applications. In order for the codes to be useful for the contemplated reactor systems, thermodynamic databases are needed for uranium-carbon, silicon-carbon, and other candidate carbide systems.

- *Thermophysical Properties:* The introduction of advanced materials for extreme high temperature applications (2000-3000K) in propulsion systems necessitates a thorough knowledge of their thermophysical properties. The most important properties for this application are thermal conductivity, density, specific heat, emissivity and chemical diffusion coefficients. The last of these is critical for the prediction of high temperature deformation behavior (creep). While calculations enable some insight into their values, confirmation by means of real measurement is essential. A critical limitation to any of these measurements is the ability to make non-contact temperature measurements, which requires knowledge of the emissivity. NASA has developed several earth- and space-based apparatus to enable measurement of thermophysical properties. These include a series of levitators for containerless processing, including acoustic, aero-acoustic, electromagnetic, and electrostatic. Techniques have been established to measure mass transport properties in the liquid in the free fall environment of space, where convection is effectively eliminated. Measurements of species diffusion have been made by means of both shear cell techniques and by means of radioactive tracers. The tremendous potential of the electrostatic levitator has recently been realized, with the possibility of examining non-conductors such as refractory oxides. These include time-temperature-transformation diagrams, and phase diagram data for supercooled liquids. Properties such as viscosity, density, and specific heat can also be measured. Species diffusion data can only be obtained in microgravity experiments. Recent developments in first principles calculations are enabling the determination of important information such as phase diagrams.

Solicited research would outline plans to determine the thermophysical properties of selected materials of interest to the space propulsion venture. This determination would include ab initio and molecular dynamics calculations, where possible, and a method of determining such properties as viscosity, density, and specific heat.

- *Mechanical Properties:* Structural applications for spacecraft propulsion systems will require materials to operate safely and reliably at high temperatures, for long durations, and under hostile environments. New, lightweight materials are needed for these applications. Materials with ordered structures at the nanometer scale ("nanomaterials") may provide the properties needed for propulsion applications. Interactions at this scale produce behavior that cannot be extrapolated from properties at higher length scales. Recently, computational methods have started to be developed which span the length scales from atomistic to continuum effects. These simulation methods can have a significant impact on nanomaterials design. However, further development is needed to produce reliable, predictive capabilities.

The target applications include prediction of creep properties for high temperature applications; the effect of environment on material integrity, particularly under radiation exposure; and life assessment under cyclic loading. These applications require effective constitutive equations for behavior of novel materials, derived from combined theoretical and experimental investigations.

III. CURRENT PROGRAM CONTENT

Materials Science for Advanced Space Propulsion is a new thrust for PSD. As such, there are no projects currently supported by PSD that have been selected specifically to focus upon these topics. NASA, under the Advanced Space Transportation Program, is supporting materials development for application to advanced space propulsion systems. However, these projects are generally working at a higher technology readiness (maturity) level and the analytical efforts are focused on safe life design, as opposed to the basic materials science research and fundamental material properties predictive methods solicited in this research announcement.

Additional information on the materials science needs of the ASTP elements can be obtained from presentations made at the Materials Science for Advanced Space Propulsion Workshop (October 2001) available at http://msad.msfc.nasa.gov/mwd.

IV. FUTURE DIRECTIONS OF THE PROGRAM

As this topic is a new initiative, it represents a future direction of the larger Materials Science Program. It is anticipated that as the propulsion systems for the 3rd Generation RLV mature, and the various options for the In-Space Propulsion Program converge to a smaller set, more specific challenges and a narrowed field of materials choices will emerge. As materials science needs for these systems are refined, the research focal areas will be adjusted to align with these objectives.

In addition, there may be opportunities for future cooperative research projects with the other PSD disciplines represented in this announcement. An excellent example of such opportunities would be with the Combustion Sciences Program future directions:

- Chemical Vapor Deposition Processing
- Chemical Vapor Infiltration Processing for Densification of Woven Materials
- In-situ Processing
- Advanced Propulsion Systems for Interplanetary Travel
- Processes for Production of Fullerenes and Single-Walled Nanotubes

In selection of future projects, while peer review for determination of technical merit and microgravity relevance will continue to be important in terms of providing a necessary condition for program selection, additional consideration will be given to how these programs fit within the framework developed for addressing the specific goals of the space propulsion systems. Further, it is very important that these activities be coordinated with those of other Government agencies funding materials science research focused on advanced propulsion systems, and that the knowledge gained for this research is transferred to industry.

V. HARDWARE AND FACILITIES DESCRIPTIONS

A. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the PSD materials science program include an array of specialized laboratory apparatus, such as laboratory equipment (i.e. furnace systems, special diagnostic tools and equipment, etc.), a drop tower at GRC, and parabolic flight research aircraft. Varieties of specialized test apparatus have been constructed and used to conduct a wide range of materials science research. In general, these apparatus have been developed to accommodate specific individual investigator's requirements. In addition, other hardware and facilities have been developed which have the potential for use by investigators. **Information on these laboratory apparatus and ground-based facilities is provided in Appendix F, Materials Science Research Program.** Investigators should denote any additional facilities needed for their research. Such facilities, if available, can be made accessible on a limited basis.

B. SPECIALIZED GROUND-BASED RESEARCH CAPABILITIES

NASA is also able to support selected Principal Investigators with state-of-the-art laboratory equipment, sample preparation facilities, and computing support. These facilities are offered on an as available basis, through the Science Directorate of the Marshall Space Flight Center, who have available trained personnel to assist all experiments. **Information on these facilities is provided in Appendix F, Materials Science Research Program**.

Additional facilities and equipment are also available within the MSFC Engineering Directorate Materials, Processes, and Manufacturing Department. A description of existing facilities can be found at the following Web sites:

https://mpm.msfc.nasa.gov/organization/ED31.htm
https://mpm.msfc.nasa.gov/organization/ED34/RP/rp_web.htm
https://www.ies.msfc.nasa.gov/ed38/main.htm
http://mpm.msfc.nasa.gov/pec/

VI. NRA FUNDING AND SCHEDULE

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

For the purposes of budget planning, we have assumed that the Physical Sciences Division will, in the materials science for advanced space propulsion area, fund approximately 10-15 ground-based study proposals from those judged to be highly meritorious (at an average of approximately $150,000 per year) for up to 4 years. At this time, due to severe resource limitations, we do not plan to make flight definition awards in the materials science for advanced space propulsion from this NRA. The initial fiscal year (FY) 2003 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts associated with the timing of the initiation of research relative to the government fiscal year. **It is particularly important that the investigator realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year.** The proposed budget for ground-based studies should include researchers' salaries, travel to science and NASA meetings (one such meeting will be a kick-off meeting to initiate coordination of the research with the propulsion system customer), other expenses (publication costs, computing or workstation costs), burdens, and overhead.

A complete schedule of the review of the proposals is given below:

Notice of Intent Due:	July 15, 2002
Proposal Due:	September 3, 2002
Final Selections:	March 2003
Funding Commences:	No sooner than July 2003

(dependent upon length of the procurement process)

VII. BIBLIOGRAPHY

Documents and Web sites that may provide useful information to Investigators are listed below:

1. Office of Biological and Physical Research Homepage at NASA Headquarters, http://spaceresearch.nasa.gov

2. Microgravity Research Program Office Homepage at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov

3. NASA Microgravity Materials Science Conference 2000 Proceedings, NASA Conference Proceedings CP-2001-210827, March 2001.

4. Microgravity Science and Applications Program Tasks and Bibliography, 2000, (and prior editions), http://peer1.nasaprs.com/peer_review/taskbook/micro/mg000/mtb.cfm

5. Proceedings of the Materials Science for Advanced Space Propulsion Workshop, Huntsville, AL, October 8 – 10, 2001. Available on the Web at http://msad.msfc.nasa.gov/mwd

Questions about this program element may be directed to the Materials Science Enterprise Scientist:

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APPENDIX H
NRA 01-OBPR-08

CERTIFICATION REGARDING DEBARMENT, SUSPENSION, AND OTHER RESPONSIBILITY MATTERS PRIMARY COVERED TRANSACTIONS

This certification is required by the regulations implementing Executive Order 12549, Debarment and Suspension, 14 CFR Part 1269.

A. The applicant certifies that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three-year period preceding this application been convicted or had a civil judgement rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or Local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or Local) with commission of any of the offenses enumerated in paragraph A.(b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or Local) terminated for cause or default; and

B. Where the applicant is unable to certify to any of the statements in this certification, he or she shall attach an explanation to this application.

C. Certification Regarding Debarment, Suspension, Ineligibility and Voluntary Exclusion - Lowered Tier Covered Transactions (Subgrants or Subcontracts)

(a) The prospective lower tier participant certifies, by submission of this proposal, that neither it nor its principles is presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from participation in this transaction by any federal department of agency.

(b) Where the prospective lower tier participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

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CERTIFICATION REGARDING LOBBYING

As required by S 1352 Title 31 of the U.S. Code for persons entering into a grant or cooperative agreement over $100,000, the applicant certifies that:

(a) No Federal appropriated funds have been paid or will be paid by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, in connection with making of any Federal grant, the entering into of any cooperative, and the extension, continuation, renewal, amendment, or modification of any Federal grant or cooperative agreement;

(b) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting an officer or employee of any agency, Member of Congress, an or an employee of a Member of Congress in connection with this Federal grant or cooperative agreement, the undersigned shall complete Standard Form - LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(c) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subgrants, contracts under grants and cooperative agreements, and subcontracts), and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by S1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

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CERTIFICATION OF COMPLIANCE WITH THE NASA REGULATIONS PURSUANT TO

NONDISCRIMINATION IN FEDERALLY ASSISTED PROGRAMS

The (Institution, corporation, firm, or other organization on whose behalf this assurance is signed, hereinafter called "Applicant") hereby agrees that it will comply with Title VI of the Civil Rights Act of 1964 (P.L. 88-352), Title IX of the Education Amendments of 1962 (20 U.S. 1680 et seq.), Section 504 of the Rehabilitation Act of 1973, as amended (29 U.S. 794), and the Age Discrimination Act of 1975 (42 U.S. 16101 et seq.), and all requirements imposed by or pursuant to the Regulation of the National Aeronautics and Space Administration (14 CFR Part 1250) (hereinafter called "NASA") issued pursuant to these laws, to the end that in accordance with these laws and regulations, no person in the United States shall, on the basis of race, color, national origin, sex, handicapped condition, or age be excluded from participating in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity for which the Applicant receives federal financial assistance from NASA; and hereby give assurance that it will immediately take any measure necessary to effectuate this agreement.

If any real property or structure thereon is provided or improved with the aid of federal financial assistance extended to the Applicant by NASA, this assurance shall obligate the Applicant, or in the case of any transfer of such property, any transferee, for the period during which the real property or structure is used for a purpose for which the federal financial assistance is extended or for another purpose involving the provision of similar services or benefits. If any personal property is so provided, this assurance shall obligate the Applicant for the period during which the federal financial assistance is extended to it by NASA.

This assurance is given in consideration of and for the purpose of obtaining any and all federal grants, loans, contracts, property, discounts, or other federal financial assistance extended after the date hereof to the Applicant by NASA, including installment payments after such date on account of applications for federal financial assistance which were approved before such date. The Applicant recognized and agrees that such federal financial assistance will be extended in reliance on the representations and agreements made in this assurance, and the United States shall have the right to seek judicial enforcement of this assurance. His assurance is binding on the Applicant, its successors, transferees, and assignees, and the person or persons whose signatures appear below are authorized to sign on behalf of the Applicant.

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